EVALUATION OF TECHNIQUES TO DETERMINE THE PRODUCTION POTENTIAL OF CULTIVATED PASTURES

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EVALUATION OF TECHNIQUES TO DETERMINE THE PRODUCTION POTENTIAL OF CULTIVATED PASTURES

by

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DECLARATION

I declare the dissertation hereby submitted by me for the partial fulfilment of the requirement for the degree of *Magister Scientiae* (Grassland Science) at the University of the Free State is my own independent work and has not been submitted by me at another university/faculty. I further cede copyright of the dissertation in favour of the University of the Free State.

Sunet Vermeulen

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ABSTRACT

For farm managers to utilize their pastures more efficiently, it is essential to estimate both herbage biomass and botanical composition. Therefore, there is a need to estimate herbage biomass and botanical composition of cultivated pastures with simple, accurate and cost-effective methods instead of the more accurate, but time-consuming destructive methods.

The objective of this study was to evaluate non-destructive methods for estimating herbage biomass and/or botanical composition on different mixed-species pastoral systems for beef and/or dairy cattle and to identify the method, if any, that would be most accurate in each particular pastoral system.

A comparison of the rising plate meter, the comparative yield method and the meter stick was conducted to determine the predictability of these non-destructive methods for estimating herbage biomass. Furthermore, the dry-weight-rank method for determining species composition was compared to hand clippings.

The accuracy of the different non-destructive methods for estimating herbage biomass was compared using the coefficient of determination (r^2) values between cut material and herbage biomass estimates. The study indicated that the meter stick (r^2 = 0.79 – 0.85) provided the most accurate values for the dairy pastoral systems. In the beef pastoral systems the rising plate meter (r^2 = 0.76 – 0.83) resulted in the most accurate method, for three out of four of pastoral systems. It was clear that species composition of the stand was an important factor affecting the accuracy of herbage biomass estimates.

Based on the results of this study, all of the non-destructive herbage biomass estimation methods tested are suitable for use on both farm-level and pasture studies on larger areas. However, in grazing studies that are conducted on relatively small areas and with a relatively small number of animals, these methods may be less accurate and where accurate herbage biomass is desired, cutting is still recommended.

Furthermore, the results indicate that the dry-weight-rank method of analysis is an accurate means of determining the botanical composition of both cultivated dairy and beef pastoral systems. The contribution of 92% and 96% of all species within the dairy and beef pastoral systems, respectively, was estimated within 5% accuracy of the “true/actual” value of species determined by hand clipping.

These methods for determining herbage biomass and botanical composition can serve as a useful tool to set stocking rates at levels necessary to balance forage supply and demand in pastures that may have uneven species composition. These measurements are essential to make sure that animals are adequately fed and swards not under- or overgrazed and therefore ensure sustainable animal production.

Key words: dry matter, herbage biomass, botanical composition, cultivated pasture, rising plate meter, comparative yield method, meter stick, dry-weight-rank method

OPSOMMING

Suksesvolle weidingbestuur vereis dat die beskikbare plantmateriaal vir beweiding en die botaniese samestelling daarvan akkuraat gemeet moet word. Hierdie inligting moet vervolgens doeltreffend in die bestuur verreken word. Daarom bestaan die behoefte om die staande droëmateriaal en botaniese samestelling van aangeplante weidings met eenvoudige, akkurate en koste-effektiewe metodes te bepaal in plaas van die meer akkurate, maar tydrowende kwadraatmetode waar die plante wel gesny word (destruktiewe metode).

Die doel met hierdie studie is om verskillende nie-destruktiewe metodes vir die bepaling van staande droëmateriaal en/of botaniese samestelling op verskillende weidingstelsels, bestaande uit gemengde plantspesies, vir vleisbeeste en/of melkbeeste te evalueer en om die metode wat in elke besondere weidingstelsel die akkuraatste sou wees, te identifiseer.

‘n Vergelyking van die skyf-weiveldmeter, ‘n visuele metode en die meterstok is uitgevoer om die voorspelbaarheid van hierdie nie-destruktiewe metodes vir die bepaling van staande droëmateriaal te bepaal. Verder is die droëmassa-rangordemetode vir die bepaling van spesiesamestelling met geoeste (destruktiewe) waardes vergelyk.

Die akkuraatheid van die verskillende nie-destruktiewe metodes vir bepaling van staande droëmateriaal is vergelyk deur die bepalingswaarde koëffisiënt (r^2) tussen die geoeste materiaal (destruktief) en bepalings deur die verskillende nie-destruktiewe metodes te gebruik. Die studie het aangetoon dat die meterstok (r^2 = 0.79 – 0.85) die akkuraatste waardes vir die melkbeesweidingstelsels verskaf. In die vleisbeesweidingstelsels was die skyf-weiveldmeter (r^2 = 0.76 – 0.83) vir drie uit vier van die weidingstelsels die akkuraatste metode. Dit was duidelik dat die spesiesamestelling van die verskillende stelsels ook ‘n belangrike faktor mag wees wat die akkuraatheid van die bepalings beïnvloed.

Gebaseer op die resultate van hierdie studie, is die getoetste nie-destruktiewe metodes vir die bepaling van staande droëmateriaal geskik vir die gebruik op beide plaasvlak en wetenskaplike weidingstudies op groter oppervlaktes. Inteenstelling waar weidingstudies op relatief klein oppervlaktes en met ‘n relatief klein getal diere uitgevoer word, mag hierdie metodes egter minder akkuraat wees. Waar akkurate bepalings verlang word, word die sny van plantmateriaal steeds aanbeveel.

Die resultate toon verder dat die droëmassa-rangordemetode van plantontleding ‘n akkurate metode is om die botaniese samestelling van beide aangeplante melk- en vleisbeesweidingstelsels te kwantifiseer. Die onderskeidelike bydrae van 92% en 96% van alle spesies in die melk- en vleisbeesweidingstelsels is bepaal binne 5% akkuraatheid vanaf die “ware/werklike” spesie voorkoms, soos bepaal met behulp van destruktiewe metode.

Samevattend kan verklaar word dat nie-destruktiewe metodes beslis as ‘n bruikbare instrument kan dien vir die doeltreffende bestuur van aangeplante weidings. Hierdie meetings is essensieel vir effektiewe dierevoeding en kan van hulp wees sodat weidings nie onder- of oorbewei word nie en sodoende volhoubare diere produksie sal verseker.

CHAPTER 1

INTRODUCTION

1.1 IMPORTANCE OF HERBAGE BIOMASS AND BOTANICAL COMPOSITION ESTIMATION

The Western Cape Province of South Africa has the potential in terms of climate and natural resources to produce efficient forage for sustainable beef and dairy cattle production systems (Botha *et al*. 2009; van der Colf *et al*. 2009). Over the last two decades a variety of cultivated pastures, homogenous stands or sown in mixtures, were used in these production systems (Botha *et al*. 2008; Botha 2009; Botha *et al*. 2009; van der Colf *et al*. 2009). However, these large volumes of information and success stories are of little value if parameters for evaluating the productivity of a pasture cannot be scientifically quantified. The most important key pasture productivity parameters include herbage biomass and botanical composition. Pasture researchers have defined herbage biomass as the total amount of herbage dry matter per ground area cut at ground level, regardless of grazing preference or availability. Whereas, botanical composition is defined as the proportions of various plant species in relation to the total on a given area (Karsten and Carlassare 2002). Therefore, to utilize their pastures more efficiently, it is essential for farm managers to estimate both herbage biomass and botanical composition for sustainable animal production (Harmoney *et al*. 1997; Sanderson *et al*. 2001).

Herbage biomass are the single most important factor for setting stocking rates, stock densities and herbage allowance in grazing systems (Gourley & McGowan 1991; Aiken & Bransby 1992). Herbage biomass estimates are also important in making management decisions for improving productivity and overall profitability of grazing systems by properly allocating resources such as labour and capital. Dairy and beef cattle farmers’ use these herbage biomass estimates as tools to plan effective pasture use in terms of: (i) time of application and quantity of fertilizer, (ii) timing of grazing, (ii) mowing time and (iv) adaptation of paddock size of their grazing systems (Schut *et al*. 2005).

Knowing the amount of available herbage biomass throughout the year allows the farm manager to make well-informed management decisions that can increase profitability, while maintaining a forage base that meets short-term animal production goals, as well as performing risk management control. Knowledge of the botanical composition of grazing systems, especially for mixed-species, is an important determinant for forage supply. Quantifying botanical composition is necessary because plants generally vary widely in their: (i) productivity (Hurd & Pond 1958), (ii) acceptability (Clary & Pearson 1969; Barnes *et al*. 1985), (ii) digestibility (van Soest 1983) and (iv) nutrient content (Minson 1982).

1.2 PROBLEM IDENTIFICATION

Herbage biomass and botanical composition as parameters for the evaluation of grazed pastoral systems is difficult to define and measure. Difficulties in estimating these parameters in specific cultivated pastures are well known (Morley *et al.* 1964; Haydock & Shaw 1975), especially when these difficulties usually magnified in highly variable pastoral systems. Most farmers, especially beef cattle farmers in the Western Cape Province, are managing mixed-species pastoral systems without sound scientific productivity measurements applied (Botha *et al*. 2009). These pastures are characterized by a diversity of species and a variability of species distribution, each with its own characteristics and productivity, which have to be taken into account in sustainable production systems.

There are a variety of destructive and non-destructive methods available to estimate herbage biomass and botanical composition (Cook & Stubbendieck 1986; Catchpole & Wheeler 1992). These methods have benefits and drawbacks, and vary in their overall level of difficulty. The basis for scientifically estimating herbage biomass and botanical composition is to clip, separate species if necessary, dry and weigh samples of a known area.

Many researchers agree that clipping provides the most accurate quantification of herbage biomass and botanical composition (Cochran 1977; Pieper 1988; Catchpole & Wheeler 1992; Benkobi *et al.* 2000; ‘t Mannetjie 2000). Unfortunately, if these parameters are carried out destructively by cutting certain areas, a large number of samples are usually needed and/or large areas have to be harvested. In solving these problems, researchers have investigated and proposed a number of non-destructive methods over the years for estimating herbage biomass and/or botanical composition of pastoral systems (‘t Mannetjie & Haydock 1963; Morley *et al.* 1964; Robel *et al*. 1970; Haydock & Shaw 1975; Bransby & Tainton 1977; Bransby *et al*. 1977; Michalk & Herbert 1977; Varth & Matches 1977; Earle & McGowan 1979; Santillan *et al.* 1979; Vickery *et al.* 1980; Sharrow 1984; Stockdale 1984a; Stockdale 1984b; Stockdale & Kelly 1984; Karl & Nicholson 1987; Friedel *et al.* 1988; Aiken & Bransby 1992; Fulkerson & Slack 1993; Gabriëls & van den Berg 1993; Douglas & Crawford 1994; Murphy *et al.* 1995; Harmoney *et al.* 1997; Virkajärvi 1999; Benkobi *et al.* 2000; Ganguli *et al.* 2000; Sanderson *et al.* 2001; Vermeire & Gillen 2001; Martin *et al.* 2005). Generally, non-destructive methods are less tedious and faster to use than destructive methods, but require some form of destructive measurement for the creation of new models, or calibration and validation of the estimates (‘t Mannetjie 2000).

Vegetation type and the specific production system also have a major impact on the accuracy of pasture productivity evaluation because various methods react differently to sward characteristics (Martin *et al.* 2005). Different cultivated pastoral systems are normally used on the Western Cape farms, of which three different dairy pastoral systems and four different beef pastoral systems are being evaluated at Outeniqua Research Farm, near George in the Western Cape Province. Therefore, a unique opportunity was created to evaluate different methods to estimate herbage biomass and/or botanical composition on these well established beef and dairy pastoral systems of this research farm.

1.3 AIM OF STUDY

The importance of sound scientific quantification of the production potential of cultivated pasture for sustainable animal production cannot be over-emphasized. Therefore, there is a need to estimate herbage biomass and botanical composition of cultivated pastures using simple and cost-effective methods instead of the more accurate, but time-consuming quadrat method.

The objective of this study were to: (i) evaluate the rising plate meter, the comparative yield method, the meter stick and the dry-weight-rank method for estimating herbage biomass and/or botanical composition on different mixed-species pastoral systems for beef and/or dairy cattle and (ii) to identify the method, if any, that would be most accurate in each particular pastoral system.

CHAPTER 2

LITERATURE REVIEW

Effective cultivated pasture management relies on regular assessment of the pasture and the ability to use these collected information for decision making at all management levels (O'Donovan *et al*. 1997). Knowledge of herbage biomass and botanical composition of pastoral systems is important for the farmer to: (i) evaluate different pasture mixtures, (ii) more effectively manipulate pasture production and botanical composition, (iii) determine stocking rates, (iv) estimate forage inventory and fertilizer needs, (v) estimate fertilization costs benefits, (vi) evaluate different management strategies and (vii) to calculate net return on investment (Galt *et al*. 2000).

Although many methods for measuring pasture production potential of cultivated pasture systems are available, the farmer or researcher should be aware of their existence, applicability and limitations. Factors affecting the choice of method are usually related to the: (i) uniformity, density, height and species composition of the pasture, (ii) the size and shape of the areas, (iii) the precision required and (iv) facilities and labour available (t'Mannetjie 2000).

Methods available for measuring herbage biomass and botanical composition of pastoral systems can be grouped into destructive and non-destructive methods ('t Mannetjie 2000). Unfortunately, all require some form of cutting or plant removal. The difference between the two groupings is that for destructive methods, the amount of vegetation of an area is estimated by cutting methods only. Non-destructive methods usually involve the measurement of one or more variables that can be related to quantity by the destructive harvesting of only a small number of sampling units.

2.1 DESTRUCTIVE HERBAGE BIOMASS ESTIMATION

Clipping is currently the most scientific and widely use method of determining herbage biomass for pastoral systems where the vegetation is primarily herbaceous and stratified into relatively homogenous types (Kucera & Ehrenreich 1962; van Dyne *et al.* 1963; Kelly *et al.* 1974; Peet *et al.* 1975; Fliervoet & Werger 1984; Towne & Owensby 1984).

2.1.1 Sampling procedure

Herbage biomass is determined in small plots (quadrats) (Figure 2.1), which are representative of the vegetation sampled (Cook & Stubbendieck 1986). Plots are clipped to a certain height aboveground level and the total fresh weight is recorded for each quadrat. Materials from small quadrats can be dried (Figure 2.2) and weighed without sub-sampling. However, with large amounts of material the fresh herbage must be weighed and a sub-sample taken immediately for drying and weighing to determine the percentage dry matter function. When sub-samples are not weighed immediately after taking, it must be kept in a moisture tight container to avoid water loss before weighing. Dry herbage biomass is then calculated by multiplying the average wet weight of herbage biomass in each subplot by the average of the dry matter obtained in each subplot.

2.1.2 Quadrats, cutting equipment and cutting height

The size, shape and number of plots harvested vary widely among studies that use clipping (Cook & Stubbendieck 1986). Quadrats are usually square, but can be rectangular or circular (Greig-Smith 1957). The appropriate size and shape depend upon the objectives and requirements for the study as well as the characteristics of the pasture sampled.

Figure 2.1 Small plots (quadrats) are clipped to a certain height to determine herbage biomass.

Figure 2.2 A sample of the cut material is dried to determine a percentage dry matter function of the herbage biomass.

Most commonly used for herbage biomass estimates are quadrangular quadrates with an area of 0.25 m^2 (‘t Mannetjie 2000). According to van Dyne *et al*. (1963), relative large (1 m^2) circular plots provide the most precise herbage biomass estimates for very heterogeneous pastoral systems. Tapes, folding rulers, sticks and even strips of paper have been used for marking quadrats. Rigid frames made of steel straps or rods, bent to desired dimensions with the ends welded together, are commonly used to mark quadrats. However, this results in a bulky and heavy piece of equipment (Donald *et al.* 1988).

Several types of hand operated tools such as scissors, shears, sickles, knives and scythes are used for plant material removal within the sampled quadrat area. Clipping is applied either on individual species basis or on the whole herbage biomass indiscriminately. A vacuum cleaner can even be incorporated with hand-held shears to collect the material clipped (van Dyne *et al*. 1963). It is essential with any type of cutting implement that cutting height aboveground level can be controlled. Hand cutting may be personal bias when more than one person does the work. The easiest way to prevent this is to use a grid within the quadrat equipped with legs of the desired cutting height. Cutting heights will vary depending on the type of pastoral system and grazing animal, ranging from 10 mm to 50 mm in closely grazed pastures to 100 mm to 200 mm in tall swards. Low cutting heights can include extraneous material such as detached litter, twigs, gravel and dry faeces. Cutting to ground level, may affect re-growth and sampling areas cut to ground level should be omitted from sampling again in the near future (‘t Mannetjie 2000).

2.1.3 Limitations of the destructive herbage biomass estimation method

Destructive sampling requires high inputs of labour and/or equipment. This can be costly and may lead to insufficient sample numbers (‘t Mannetjie 2000). For most farmers destructive sampling is just not a practical tool because of the money and time investment required for accurate estimates. Errors can be introduced from inconsistencies among observers in stubble clipping height, the determination of what vegetation is considered to be included in the measured area, and the extrapolation of plot estimates to a larger area (‘t Mannetjie 2000). Estimates derived through clipping cannot be viewed in the field because of the time required to oven dry the vegetation which limits the use of this method when immediate decisions are required. Destructive sampling also prevents measuring changes of the sward in the sampling area. In small grazed plots the material removed may be a significant proportion of the feed available. Some investigations may also demand non-destructive sampling because destructive sampling may not be permitted (‘t Mannetjie 2000). For these reasons non-destructive herbage biomass estimation methods have been developed over the years.

2.2 NON-DESTRUCTIVE HERBAGE BIOMASS ESTIMATION

While destructive sampling is the most accurately used method of determining herbage biomass, it is costly and time consuming. Using this method allows individual samples to be measured accurately, however the samples collected only represent a small area out of a large and sometimes highly variable sward (Haydock & Shaw 1975; Harmoney *et al.* 1997; Sanderson *et al.* 2001; Martin *et al.* 2005). The problem with measuring herbage biomass usually lies with the variability of the sward and not with the precision of the measurement and is therefore better to take many samples with less precision than a few measured precisely (Haydock & Shaw 1975). To increase the number of samplings and to reduce the time spent in taking them, faster non-destructive methods have been developed. Although non-destructive methods are less accurate on a per sample basis than destructive sampling, non-destructive methods take less time per observation and involve less physical effort by the operators. Thus, when compared with destructive methods, herbage biomass may be estimated more accurately even though the herbage biomass of each quadrat is measured less accurately. The larger number of quadrats also offers more opportunity for examining spatial heterogeneity.

Researchers have investigated and proposed a number of non-destructive methods over the years (Morley *et al.* 1964; Robel *et al*. 1970; Haydock & Shaw 1975; Bransby & Tainton 1977; Bransby *et al*. 1977; Michalk & Herbert 1977; Vartha & Matches 1977; Earle & McGowan 1979; Santillan *et al.* 1979; Vickery *et al.* 1980; Sharrow 1984; Stockdale 1984; Stockdale & Kelly 1984; Karl & Nicholson 1987; Friedel *et al.* 1988; Aiken & Bransby 1992; Fulkerson & Slack 1993; Gabriël & van den Berg 1993; Douglas & Crawford 1994; Murphy *et al.* 1995; Harmoney *et al.* 1997; Virkajärvi 1999; Benkobi *et al.* 2000; Ganguli *et al.* 2000; Sanderson *et al.* 2001; Vermeire & Gillen 2001; Martin *et al.* 2005) Non-destructive methods use a double sampling function by developing a regression relationship of herbage biomass to predictive variable such as height, leaf area, vegetation density and age cover or visual obstruction through a small amount of destructive sampling (Cochran 1977). When a relationship has been developed, less emphasis is placed on clipped samples, using them only for calibration and validation within trials (Ganguli *et al.* 2000). Non-destructive methods for estimating herbage biomass should meet several criteria of which include: (i) accuracy, (ii) rapidness, (iii) minimum calibration and (iv) unaffected by environmental circumstances such as mist, dew, wind, clouds, varying irrigation condition and uneven micro topography (Tucker 1980). The instruments should be light, sturdy, easy to carry, reliable and inexpensive (Tucker 1980). It is doubtful if any one method will meet all the desired criteria.

2.2.1 Limitations of current non-destructive herbage biomass estimation methods

Although non-destructive methods overcome some problems, they introduce a host of others, such as calibration errors, observer variability and incorrect applications that make them invalid for intended applications (Earle & McGowan

1979; Aiken & Bransby 1992; Virkajärvi 1999; Donkor *et al*. 2003). All non-destructive methods depend on the reliability of the relationship between a measurement and the actual amount of herbage biomass present. In non-destructive pasture sampling the regression may vary from locality to locality, cut-to-cut, paddock-to-paddock or even species to species within a trial. The date of sampling can affect the accuracy of the herbage biomass estimation methods (Virkajärvi 1999). This is attributed to seasonal changes in the swards botanical composition, the plants phonological stage of development and herbage accumulation of dead material (Donkor *et al*. 2003). The leaf surfaces may be wet or dry depending on the time of day or recent rainfall and soil moisture levels may vary affecting the moisture content within the plant. The observer also constitutes another source of variation (Earle & McGowan 1979; Aiken & Bransby 1992). Aiken & Bransby (1992) observed significant differences in measurements of the same grass bulk measured by four different observers, and in the selection of the representative sampling area. Earle & McGowan (1979) also reported significant variability between observers and they recommended that the same operator should take meter readings on calibration in pasture measurements. However, it is possible that among observer variation can be reduced through the training of observers (Aiken & Bransby 1992).

Accuracy of the same herbage biomass estimation method may differ between before and after grazing (Murphy *et al*. 1995). Murphy *et al*. (1995) compared cutting of quadrats, capacitance meter, a sward stick and rising plate for estimating herbage biomass on pasture of smooth-stalked meadow grass (*Poa pratensis*) and white clover (*Trifolium repens*) in a rotational stocking experiment. Correlation coefficients (r^2) between cut quadrats and pre- and post-grazing herbage biomass estimates were 0.65 and 0.36 for the capacitance meter, 0.70 and 0.31 for the sward stick and 0.72 and 0.05 for the rising plate meter, respectively. Very short (25 mm – 50 mm) residue could probably affect the ability of a non-destructive method to correctly measure herbage biomass (Murphy *et al*. 1995). In relative uniform stands of single herbage species or two species mixture non-destructive herbage biomass estimation methods can be effective, while in mixed species stands the same method may be less consistent (Harmoney *et al*. 1997; Martin *et al*. 2005). Martin *et al*. (2005) found that the rising plate meter was most effective method for estimating herbage biomass in beef pasture, and the meter stick was most effective in dairy pasture, for both pre- and post grazing.

Many commercial available biomass sampling devices are accompanied by universal calibration equations that may be misapplied if they were developed in different regions with different vegetation. Poor relationships between herbage biomass and biomass calculated with universal equations on grass-legume mixtures for commercial capacitance meters, rising plate meter and sward stick were observed in studies (Earle & McGowan 1979; Sanderson *et al.* 2001). The authors concluded that, at the very least, regional specific calibrations should be made to improve accuracy and precision (Earle & McGowan 1979; Sanderson *et al.* 2001).

Each situation will have an affect on the relationship between the instrument reading and the amount of pasture present. If any of these variations occurs, the only way of estimating herbage biomass accurately may involve the paradox of taking more samples for calibrations than would be needed for the destructive sampling process itself in the first instance. The success of any non-destructive method will clearly rest in its ability to confront this paradox (‘t Mannetjie 2000).

2.2.2 Comparison of existing non-destructive herbage biomass estimation methods

Over the years researchers and farmers used visual estimation methods, falling plates, rising plates, capacitance meters, sward sticks, calibrated gumboots and in more recent years light/sound absorption or reflection and satellites to estimate herbage biomass of pastures (Robel *et al*. 1970; Haydock & Shaw 1975; Bransby *et al*. 1977; Michalk & Herbert 1977; Vickery *et al*. 1980; Sharrow 1984; Bartham 1986; Murphy *et al.* 1995; Harmoney *et al.* 1997; Virkajarvi 1999; Benkobi *et al.* 2000; Sanderson *et al.* 2001; Vermeire & Gillen 2001). The simplest instruments are the pasture ruler and the sward stick (Barthram 1986; Harmoney *et al.* 1997), which measure plant height rather than compressed sward height. However, canopy height can be difficult to measure due to the subjectivity associated with measurements and disagreement over which plants or plant parts should be considered to form a mean canopy estimate (Heady 1957). Researchers have added several types of discs or plates to the ruler in order to incorporate an area dimension to the measurement and thereby increase the sample point area (Whitney 1974; Bransby *et al*. 1977; Sharrow 1984).

Visual obstruction methods (Robel *et al*. 1970) have been considered in some comparative studies to be good methods for non-destructive estimation in comparison with the previously described methods (Michalk & Herbert 1977; Harmoney *et al*. 1997; Benkobi *et al*. 2000; Vermeire & Gillen 2001). Visual obstruction has been used to estimate herbage biomass in tall grass prairie (Robel *et al*. 1970; Vermeire & Gillen 2001) and improved pastures (Harmoney *et al*. 1997). Robel *et al*. (1970) accounted for 95% of the variation in tall grass prairie herbage biomass, whereas Harmoney *et al*. (1997) accounted for 63% of the variation in improved pasture herbage biomass. However, there is little reference in the literature and investigations on the performance of this method in different vegetation types are limited (Ganguli *et al*. 2000). More complex electronic instruments are the electronic capacitance meter (Vickery *et al*. 1980; Crosbie *et al*. 1987) and the sonic sward stick (Hutchings 1990). Readings from these instruments are, however, affected by water in the vegetation, including litter, and often such instruments come with standard equations that are not adjusted to particular localities and conditions (Frame 1993).

In Table 2.1 a comparison is given between regression models obtained from several authors in various pasture types for non-destructive herbage biomass estimation methods. The visual obstruction method resulted in the highest r^2 value (0.86), followed by the plate meter (0.80), capacitance meter (0.73), visual estimation method (0.65), canopy height (0.61), and the leaf analyser (0.40). The above information resulted into an in detail look at a rising plate meter, visual estimation method (comparative yield method) and meter stick for estimating herbage biomass non-destructively.

Table 2.1 Mean best regression coefficients (r^2) found in the literature for herbage biomass estimations by the most widely used measurement methods.

Method	**Mean r^2**	**Authors**
Visual Obstruction	0.86	Robel *et al.* 1970; Harmoney *et al.* 1997; Ganguli *et al.* 2000; Benkobi *et al.* 2000; Vermeire & Gillen 2001
Plate meter	0.80	Bransby *et al.* 1977; Michell 1982; Michell & Large 1983; Stockdale & Kelly 1984; Gabriëls & van den Berg 1993; Douglas & Crawford 1994; Murphy *et al.* 1995; Harmoney *et al.* 1997; Virkajarvi 1999; Ganguli *et al.* 2000; Martin *et al.* 2005; Ogura *et al.* 2005
Capacitance meter	0.73	Michell & Large 1983; Stockdale & Kelly 1984; Murphy *et al.* 1995; Virkajarvi 1999; Ogura *et al.* 2005
Visual estimation	0.65	Cambell & Arnold 1973; Haydock & Shaw 1975; Martin *et al.* 2005
Canopy Height	0.61	Alexander *et al.* 1962; Griggs & Stringer 1988; Murphy *et al.* 1995; Harmoney *et al.* 1997; Gonzalez *et al.* 1990; Virkajarvi 1999; Ganguli *et al.* 2000; Martin *et al.* 2005; Ogura *et al.* 2005
Canopy Analyser	0.4	Harmoney *et al.* 1997; Ganguli *et al.* 2000

2.2.2.1 Rising plate meter

Forage bulk refers to the volume of herbage compressed beneath a plate or disc of known weight (Bransby *et al*. 1977). A measurement is taken by dropping a plate or disc from a predetermined height above the soil surface after which the height at which the plate or disc comes to rest is measured. The relationship between forage bulk and herbage biomass generally has been strong. Correlation coefficients greater than 0.90 have been reported (Alexander *et al*. 1962; Shrivastava *et al*. 1969; Powel 1974; Castle 1976; Bransby *et al*. 1977; Santillan *et al*. 1979). Because forage bulk is a measure of compressed volume of the herbage, it integrates both sward height and density into a single, three-dimensional quantity. This is believed to explain its value as a predictor of herbage biomass (Alexander *et al*. 1962; Michalk & Herbert 1977).

Several different instruments have been used to measure forage bulk. The earliest instruments used were simple and included a plywood plank (Alexander *et al*. 1962), a rigid weighted sheet and a cardboard box (Shrivastava *et al*. 1969) that was dropped on the vegetation canopy and its mean height determined by measuring the height of each side's midpoint. Instruments that are now more commonly used include weighted discs and plates that are either dropped or allowed to settle on the canopy (Santillan *et al*. 1979). Another variation of this instrument is a rising disc or plate meter. Rising plate meters allow vegetation to push a plate or disc up a pole it is supported on, as it is lowered into the vegetation.

(i) Sampling procedure

The rising plate meters consist of a round or square disc/plate made of light metal or of plastic foam of a given weight that can slide along a central rod, which is lowered or dropped from a fixed height onto the sward (Figure 2.3). When taking measurements the shaft is held 10 cm or more above the top of the pasture and placed on the grass. While the shaft is placed on the grass the disc/plate stops going downwards when it settles. The height aboveground level at which it rest is either noted from a scale on the rod, recorded on counters, or automatically recorded on an attached small computer, which also calculates the mean of a number of readings (‘t Mannetjie 2000).

(ii) Calibration procedure

Sampling for calibration purpose involves taking a reading with the meter and placing a shallow metal cylinder corresponding the size of the disc or plate over the area sampled while the instrument is still in position. The cylinder is then pressed down to the ground as firmly as possible and all the material within the cylinder is clipped once the meter has been removed (Figure 2.4) (Bransby & Tainton 1977).

This sampling method ensures that only the material immediately under the plate is harvested, whether it is rooted inside or outside the area. Dry weight is determined for each sample and the mean plant-water content is determined. The weight of dry matter is calculated as yield in kilograms per hectare (kg ha^{-1}) (Bransby & Tainton 1977). Dry matter yield is related to height in centimetres by the linear model:

$$y = mx + c$$

where height/density (x) of the plant is a variable of the dry matter yield (y) of the plant. The usual regression models are linear. However, some studies with the rising plate meter showed an exponential response in highest values of the meter values (Bransby *et al*. 1977; Baker *et al*. 1981). Once the data are collected, simple linear regressions can be used to compute the best possible equation, such that herbage biomass from resting height can be predicted (Sharrow 1984). A number of reports have indicated good relationships between herbage biomass and sward height measurements using a rising plate meter (Bransby & Tainton 1977; Stockdale 1984b; Douglas & Crawford 1994), with the meters generally sensitive to minor changes in herbage mass (Michell 1982).

(iii) Limitations of the rising plate meter

Linear regression relationships between meter readings and pasture dry matter may be affected by a number of different factors. The meter should therefore be calibrated for each specific set of conditions in which it is to be used (Bransby & Tainton 1977). Each calibration should further be supplemented with notes that draw particular attention to any departures from the standard procedure (Bransby & Tainton 1977). The pasture type should also be fully described in terms of species and morphological stage of growth. If the pasture is being grazed a note should be made of the type of animal involved as well as any other possible influencing environmental factors (‘t Mannetjie 2000).

In some experiments the relationship between herbage biomass and meter readings has been relative constant for extended periods within seasons, especially over the winter (Phillips & Clarke 1971; Earle & McGowan 1979) although the relationship commonly varies between seasons (Phillips & Clarke 1971; Powell 1974; Bransby *et al*. 1977; Varth & Matches 1977). Many researchers reported that different calibration relationships for different times of the year are attributed to the differences in dry matter percentages and the difference in species compositions in the same swards between seasons (Phillips & Clarke 1971; Powell 1974). Weather conditions like ground frost, windy conditions, heavy rain and wet conditions, also have an impact on the accuracy of the rising plate meter.

Figure 2.3 Rising plate meter consisting of a round light metal disc that can move along a central rod, which is dropped from a fixed height onto the sward.

Figure 2.4 All material within the sampled cylinder is clipped to a certain height once the meter has been removed for calibration purposes.

Researchers who use these meters need to calibrate their models when moving to different vegetation types or pasture (Santillan *et al*. 1979; Baker *et al*. 1981) and when the vegetation changes in growth form (Baker *et al*. 1981). Correlations between herbage biomass and meter readings are also greater in short-grass areas (Murphy *et al*. 1995; Stewart *et al*. 2001), areas with fewer species and areas with constant grazing pressure (Karl & Nicholson 1987). Researchers have noted variability caused by ground roughness (Earle & McGowan 1979) and plant lodging (Michalk & Herbert 1977). The meter is best used in pastures with no dead matter accumulated from under grazing or trampling (Varth & Matches 1977; Karl & Nicholson 1987). Accumulation trends and herbage biomass from the meter readings can also generally imprecise as the herbage becomes more bulky and relatively mature (Douglas & Crawford 1994).

There is variability between operators measuring the vegetation with the rising plate meters (Earle & McGowan 1979, Aiken & Bransby 1992). The variation appears to be due to different techniques adopted by the operators in using the rising plate meter. Meter readings for calibrations samples should be taken by the same operator who does the actual pasture measurements (Earle & McGowan 1979) or by standardizing the method of use between the operators through training (Aiken & Bransby 1992). Incorrect operator technique will also cause inaccurate readings. The main operators' problem is extra pressure applied to the meter when taking a measurement. By creating extra force, slamming the plate down or using the meter as a walking stick, the plate falls faster and the shaft can be pushed below the soil surface (Santillan *et al*.1979). When taking readings the following will need to be considered to ensure consistent measurement: (i) avoid gateways, troughs and fence lines, (ii) ensure the walk gives a fair representation of the paddock and (iii) the readings should be random and not biased by the operator looking where to place the meter.

Another source of error in herbage biomass estimation is achieving a constant height of cutting standard cylinders for calibration. This problem is particularly important when using hand cutting, above-ground harvesting system when it is possible for different operators to cut at different heights and for one operator to cut at different heights on different occasions. Problems in achieving a constant cutting height at different times will normally show up as erratic behaviour of the intercept (Michell 1982). If the meter is to be used in grazing studies, clipping height should be below grazing height (Bransby & Tainton 1977).

Overall the rising plate meter is inexpensive, simple to construct (Castle 1976) and can be used to make rapid biomass estimates of standing herbage (Bransby & Tainton 1977). Once the calibration is done it is a fast and simple method that can be done by unskilled persons. An operator can be trained in a short time (Aiken & Bransby 1992). The instrument can also be used to cover large areas to ensure a good representative sampling of the area in which the yield estimations are done (Castle 1976).

2.2.2.2 COMPARATIVE YIELD METHOD

Visual estimation is the least expensive and quickest method for determining herbage biomass (‘t Mannetjie 2000). In its simplest form an observer makes an estimate of the total amount of herbage biomass present, without any checks on the actual herbage biomass. Although there are observers who possess such ability to a high degree, the procedure is of doubtful value in critical research, because it is entirely subjective and lacks repeatability (‘t Mannetjie 2000). Visual estimates can be transformed to actual weights by the use of a calibration method (Morley *et al*. 1964). Visual estimates are calibrated by regress actual herbage biomass on estimated herbage biomass (Wilm *et al.* 1944). The first visual estimation method acceptable in critical research (Pehanec & Picford 1937) has since been used with numerous modifications and varying success

(Wilm *et al.* 1944; Morley *et al.* 1964; Hutchingson *et al.* 1972; Campbell & Arnold 1973; Haydock & Shaw 1975).

The comparative yield method is a form of visual estimation and was developed in Australia during the 1970's as a rapid method to estimate total biomass when sampling quadrats (Haydock & Shaw 1975). Herbage biomass is scored relatively to a set of reference quadrats that are established at the start of sampling (Haydock & Shaw 1975). It is believed that relative weight is easier to estimate than absolute weight, which will lead to greater precision and reduced training time as well as time spent on sampling (Despain & Smith 1989). The comparative yield method works best for herbaceous vegetation but can also be used successfully with small shrubs and half-shrubs (Kelly & McNeil 1980). In heterogeneous communities such as veld it has an advantage over the pasture plate meter (Bransby & Tainton 1977) in that it is less affected by the variability in morphological structure of the component species. Comparative yield method is also well suited to sampling large areas because of its rapidity (Kelly & McNeil 1980). The comparative yield method has application in experimental work involving small areas where numerous treatments are involved and/or measurements need to be made at frequent intervals (Kelly & McNeil 1980)

(i) Sampling procedure

In general the comparative yield method involves comparing the total herbage biomass in a sample quadrat to one of five reference quadrats. The five reference quadrats are set up to represent the range of weights likely to be encountered at the sample site ranging from quadrat 1 (Figure 2.5), which represents the least amount of biomass present on site to quadrat 5 (Figure 2.6), which represents the largest amount of biomass on the site (Haydock & Shaw 1975). At each quadrat placement during sampling, the quadrat is mentally or directly compared to the standard and given ranking corresponding to the appropriate standard (Haydock & Shaw 1975). Photographs of the standards could be carried and used as an aid in rating. Photographs prove to be helpful and one would expect that there would be less possibility of bias and less time spent checking with the standards (Haydock & Shaw 1979).

Sampling may be conducted in conjunction with observations of other attributes, such as frequency and the dry-weigh-rank method (‘t Mannetjie & Haydock 1963). The combination has proved to be accurate, rapid and effective in dealing with large experimental areas, but also for small plots or enclosures (Waite 1994). The combined use of the dry-weight-rank method and the comparative yield method improves efficiency and also improves the accuracy of estimating percentages. Efficiency is increased because more parameters are dealt with in one quadrat at the same time and accuracy is increased because of a possible relation between herbage biomass and species combination.

(ii) Calibration procedure

For regression analysis all five-reference quadrats are clipped and weighed to compare how close the selections are to a linear distribution of quadrat weights. The process is usually repeated with appropriate adjustments until the weights of the standards are approximately linear and all the observers are confident of their ability to place quadrats in situations representative of each rank standard (Haydock & Shaw 1979). If standards are not properly or consistently selected, such that ranks are linear, precision of the comparative yield method will be reduced (Despain & Smith 1997).

At the conclusion of sampling, another set of quadrats is scored, clipped, dried and weighed. These may be selected and clipped during sampling from among the regular sample quadrats, or they may be subjectively located and ranked after sampling is completed. The latter approach is often the preferred method as to avoid carrying clippers and bags throughout the regular sampling (Haydock & Shaw 1979).

Figure 2.5 An example of a quadrat 1, which represents the least amount of biomass present at sampling site.

Figure 2.6 An example of a quadrat 5, representing the largest amount of biomass.

Quadrats selected for harvesting should cover the range of ranks given during sampling and the majority of species encountered during sampling. The number of samples selected for calibration data set depends on the observer's ability to furnish accurate visual estimates and the variability of the biomass estimates (Haydock & Shaw 1979). Regression analysis is used to compare scores and harvested values of the calibration samples, which allows data collected from the sample quadrats to be converted to actual biomass. To ensure a representative reference, a new set of reference quadrats should be established at each new site and separate calibration samples should be harvested for each distinct sampling period. Overall, new calibration samples must be taken whenever the standards are changed. If there is more than one observer, separate sets of calibration quadrats should be harvested for each observer, or all observers should independently rank the quadrats to be harvested (Haydock & Shaw 1979).

(iii) Limitations of the comparative yield method

The accuracy of the comparative yield method depends primarily on the skill of the observer and the efficiency of the sampling procedure. The effect that fatigue and previous experience can have on subsequent observation and the variation that can occur between observers is major factors affecting the accuracy of any visual estimation method (Morley *et al.* 1964). Trained observers are clearly superior and adequate training can help reduce these problems (Morley *et al.* 1964; Campbell & Arnold 1973).

2.2.2.3 METER STICK

Herbage biomass of pastoral systems is related to the height and density of its individual components ('t Mannetjie 2000). Mostly producers do a visual evaluation and assume the taller the pasture the greater the herbage biomass. Pasture height can be measured more subjectively with a meter stick (ruler) or a graduated reference board (Heady 1957; Michalk & Herbert 1977).

(i) Sampling procedure

Meter sticks simply measure the canopy height and assume the herbage biomass is directly related to canopy height only (Figure 2.7). Canopy height measurements have been used to characterize canopy attributes such as growth, vigor, adaptability, resistance and aboveground biomass (Heady 1957). The canopy height measurements is taken as the natural undisturbed height of the pasture plants adjacent to the meter stick, not stretched or extended (Martin *et al*. 2005). Both bare spots and dense spots must be recorded and avoiding spots will usually lead to a biased average height value and miscalculated herbage biomasses.

(ii) Calibration procedure

The relationship between height and herbage biomass is determined by calibration. Calibration of the meter stick requires comparing measurements to hand clipped samples. Sampling for calibration purposes involves taking a certain amount of measurements with the meter stick within a quadrat area. All material within the quadrat is clipped to a certain height (Figure 2.8). The weight of the dry matter herbage biomass is related to the meter stick in centimeters by the linear model:

$$y = mx + c$$

where height (x) of the plant is a variable of the dry matter herbage biomass (y) of the plant.

Figure 2.7 Meter sticks measure the canopy height of the vegetation.

Figure 2.8 Material within the quadrat area is clipped.

Simple linear regressions, obtained from data collected, can be used to compute the best possible equation, such that herbage biomass from canopy height can be predicted. Commercial calibration for meter sticks is frequently developed for all kinds of pasture species and pastoral systems in all parts of the world. Research has shown that meter sticks require frequent and site-specific calibrations (Sanderson *et al*. 2001). Therefore calibration of canopy height and herbage biomass needs to be established for each specific type of pasture under study, or before every sampling event when the structure of the herbage changes. The estimated will also only be as good as the samples taken. Sample numbers are key to obtaining good estimates. Multiple measurements with the meter stick will help to improve the accuracy of this specific method for estimating herbage biomass (Martin *et al*. 2005). A higher number of measurements should be made for pastures with variable soils, topography or herbage stands.

(iii) Limitations of the meter stick

Many factors impede the measurement of pasture height. Plant height is not easily defined and measurements are thus more subject to bias and error (Symons & Jones 1971). Plant height can be difficult canopy characteristics to measure because it is often hard to determine and disagreement can exist over which plants or plant parts should be considered to form an estimate of mean canopy height (Heady 1957). The highest point may also be difficult to identify when plants are trailing or drooping, when the point and when several parts are nearly the same height (Heady 1957). Herbage biomass varies so greatly among species in pasture of differing plant densities and over the grazing season and this can result in the relationship of a pasture average height to its herbage biomass to be not very consistent, and only moderately accurate. Using pasture height alone also has limited application in yield prediction because one only measures herbage in the vertical direction (Spedding & Large 1957; van der Schaaf 1957).

Many researchers agree that meter sticks are highly inaccurate in estimating herbage biomass (Harmoney *et al*. 1997; Sanderson *et al*. 2001). However, in terms of time requirements pasture height measurements reduce time input when compared to clipping (Bakhuis 1960; Michalk & Herbert 1977). The accuracy of the meter stick can be improved by investing more time in recording additional height measurements per sampled area (Fulkerson & Slack 1993).

2.3 NON-DESTRUCTIVE BOTANICAL ESTIMATION METHOD

Botanical composition is the proportions (%) of various plant species in relation to the total on a given area. It may be expressed in terms of relative cover, relative density or relative weight. Measurement of species composition of vegetation is fundamental for pasture research and monitoring. Knowledge of botanical composition of pastoral systems is important for the farmer to: (i) have a clear indication of the diversity and dominance in the plant community, (ii) evaluate different pasture mixtures, (iii) more effectively manipulate pasture production and botanical composition and (iv) estimate forage availability for animals with different feeding habits.

Various methods are available to describe the botanical composition of grazed systems quantitatively (Tothill *et al.* 1978). Which method is used depends largely on the information required and the constraints of time and money. Measurements of species composition most often used include: (i) density, (ii) frequency, (iii) cover and (iv) dry-weight. Of these methods, composition based on dry weight is considered to be the best indicator of species importance and impact within the plant community (Daubenmire 1959). The standard for scientifically quantifying botanical composition in terms of dry-weight is to harvest, separate, dry and weigh plant species or species groups in a representative sample of sufficient sampling units. However, this method is destructive, time consuming, labour intensive and expensive. As with destructive herbage biomass estimation methods, there may be circumstances that prevent this type of destructive sampling for estimation of botanical composition.

A far less time-consuming method than destructive methods is subjective direct estimates of the dry-weight percentages of the species. This method is less objective (Tothill 1978), but it has been successfully applied and gives skilful observers the opportunity to correct for unintended biases of more objective methods. A compromise between subjectively estimating and objectively measuring is the dry-weight-rank method (‘t Mannetjie & Haydock 1963).

2.3.1 DRY-WEIGHT-RANK METHOD

The dry-weight-rank method for the analysis of botanical composition of pastures was developed in Australia to quickly and accurately estimate species composition of grassland swards on a dry weight basis (‘t Mannetjie & Haydock 1963). The only methods available earlier were either hand sorting of hand cut samples, which are labor intensive, or estimation by eye, which are not reliable. Statistical tests have demonstrated the dry-weight-rank method’s robustness (Sandland *et al*. 1982) and it has been widely applied (Tothill *et al*. 1987; Kelly & McNeil 1980; Barnes *et al.* 1982; Gillen & Smith 1986; Friedel *et al*. 1988). The practicalities of the dry-weight-rank method have motivated the development of further research either to improve its applicability, use and accuracy or to drive the discussion of the theoretical assumption behind the derivation of its coefficients (Tothill 1978; Jones & Hargreaves 1979; Sandland *et al*. 1982; Gillen & Smith 1986; Scott 1986; Hargreaves & Kerr 1987; Friedel *et al*. 1988; Neuteboom *et al*. 1998; Nijland 2000).

Although originally developed for tropical grassland, the dry-weight-rank method has been used extensively under different climatic conditions and a broad range of vegetation types. The dry-weight-rank method is well suited for monitoring vegetation changes in floristically diverse grasslands with dominant species often in moderate dry weight proportions and species usually growing in patches

(Neuteboom *et al*. 1988), like small shrub types and under-story of wooded types (Smith & Despain 1997). It is not very useful in chaparral or very sparse desert shrub types (Smith & Despain 1997), very heterogeneous South African thorn-veld (Walker 1970) and recently sown grasslands (Neuteboom *et al*. 1998) where random plant distribution can occur (van Loo 1991).

(i) Sampling procedure

With the dry-weight-rank method for botanical analysis in pastures, the dry weight proportions of species are estimated from their first, second and third ranks in dry weight in single quadrats. The dry-weight-rank method is similar as direct estimation of composition by species except that the observer only ranks the three species, which contribute the highest percentage to the weight of the quadrat. Since it is not necessary to rank all species and because it is usually much easier to determine whether a species occupies a larger or smaller part of the vegetation mass, than to estimate the weight percentages on an interval scale, the dry-weight-rank method is faster than direct estimation of composition. However, all species present can be listed if frequency is desired (Ratliff & Frost 1990).

Quadrat size is fairly flexible (‘t Mannetjie & Haydock 1963; Barnes *et al*. 1982; Neuteboom *et al*. 1988; Smith & Despain 1997) and when frequency, canopy cover or comparative yield methods are combined with the dry-weight-rank method, the requirements of these methods should govern selection of quadrat size. A basic assumption is that there should be at least three species encountered in a high percentage of quadrats, preferably all of them. Quadrat size should be small enough to enable ranks to be allocated quickly and accurately by the observer (‘t Mannetjie & Haydock 1963; Barnes *et al.* 1982). Theoretically rectangle quadrats should provide a higher number of species per quadrat than square or circular quadrats, since they are less apt to be occupied by one large plant or clump of plants of the same species (Smith & Despain 1997). Quadrats may be located by any manner, random, systematic grid or in transects (Smith & Despain 1997). As with any other sampling method, some type of randomisation is needed for statistical analysis of the data. The number of sample units depends on the variability of the vegetation with respect to quadrat size and shape. It is likely that in fairly uniform vegetation, 25 to 50 quadrats may give a repeatable estimation of composition of the major species (Despain & Smith 1997).

(ii) Multipliers

The dry-weight-rank method calculates for each species its dry weight proportion (dry-weight A% for species A) from the percentages of cases it takes the first (A1%), second (A2%) and third (A3%) rank in sampling quadrats on the basis of dry weight. The core of the methodology consists of a set of coefficients that are multiplied by the relative frequencies of the ranks assigned to each species. The multipliers are 0.70, 0.21 and 0.09 ('t Mannetjie & Haydock 1963) and added according to:

$$DWA\% = 0.702\ (A1\%) + 0.211\ (A2\%) + 0.087\ (A3\%)$$

The multipliers were derived by means of linear multiple regressions using sets of data from which the exact dry weight proportions of all species were known. The dry-weight-rank method aims to eliminate the need to develop predictive models for individual species by using multipliers that apply to a large range of pasture types and species. It has been suggested a new set of multipliers should be developed for each vegetation type (Hughes 1969). Many researchers obtained similar multipliers (Jones & Hargreaves 1979; Barnes *et al.* 1982; Kelly & McNeil 1985; Gillen & Smith 1986) to the originally derived multipliers of t' Mannetjie & Haydock (1963). Calculation of new multipliers would reduce the simplicity of the method and procedures have been developed to adapt the original multipliers to a wider range of vegetation types (Jones & Hargreaves 1979).

(iii) Limitations of the dry-weight-rank method

There are two problems with fixed multiplier ranking, although in most grazed systems they do not arise. One restriction is that the calculated dry weight can never exceed the value of 70.2%. Thus making the dry-weight-rank method not suited for pastures that are homogeneous at quadrat level and where a species consistently comprise more than 70% of yield in the quadrats (‘t Mannetjie & Haydock 1963). Species forming monospecific patches tend to be underestimated. This problem can be lessened by correction for missing ranks (‘t Mannetjie & Haydock 1963), or by assigning more than one rank to the dominant species (Tothill 1978; Jones & Hargreaves 1979). The latter solutions is referred to as cumulative ranking and suggest that when the problem arises one should either: (i) attach a first and third rank if the estimated weight lies between 75% and 85%, (ii) attach a first and second rank if the estimated weight lies between 85% and 95% or (iii) attach a first, second and third rank if the estimated weight is more than 95% (Jones & Hargreaves 1979). This does indeed raise the maximum possible percentages and has been found to increase the precision of botanical composition estimates (Jones & Hargreaves 1979).

A second potential problem arises if there is a consistent relationship between quadrat yield and the order that a species is ranked. The weighing factor used in calculating percentage composition treats all the sampling quadrats as if they weigh the same. If a particular species always takes first rank in high yielding quadrats and another one always takes first rank in low yielding quadrats, the former will be underestimated and the latter overestimated. If this situation occurs it can be corrected by applying a weighting factor for the multipliers, based on the standing herbage within the sampling quadrats (Tothill 1987). A weighting factor or actual quadrat weights can be applied to estimated proportions of species to provide an index or estimate of standing herbage by species. Quadrat weighting of the dry-weight-rank method improved species proportion in some studies (Jones & Hargreaves 1979; Sandland *et al*. 1982;

Dowhower *et al*. 2001). However, in both tallgrass prairie (Gillen & Smith 1986) and arid rangeland (Friedel *et al*. 1988) studies, there was no improvement in estimation of standing herbage composition using quadrat weighing with the dry-weight-rank method. There are two drawbacks to weighing by quadrat yield namely (i) an additional rating must be made, which requires extra time and is itself subject to error and (ii) data must be taken on an individual quadrat basis rather than by simply tallying.

Species proportions using the dry-weight-rank method derived by trained evaluators were highly correlated ('t Mannetjie & Haydock 1963; Walker 1970; Gillen & Smith 1986; Everson & Clarke 1987; Friedel *et al*. 1988; Neuteboom *et al*. 1998). Difficulties may arise because of large possible differences in dry matter content between species, and because some species are more prominent to the eye than others and tend to be overestimated (Neuteboom *et al.* 1998). Some experience in weight estimating is highly desirable so that the observers have some experience in differences in plant weight associated with plant-water content, plant morphology and phenology.

CHAPTER 3

STUDY AREA AND EXPERIMENTAL PROCEDURES

3.1 STUDY AREA

The research was conducted at Outeniqua Research Farm (Figure 3.1) near George (33º58’38’’ S; 22º25’16’’ E; altitude 201 m above sea level), which is part of the Department of Agriculture Western Cape, South Africa. The total farm area is 300 hectare (ha) with 80 ha permanent irrigation, 120 ha supplementary irrigation and 100 ha dry land.

Figure 3.1 Aerial photo of the Outeniqua Research Farm and surroundings.

3.2 CLIMATE

The study area has a mean annual rainfall of 729 mm year^{-1} (mean for 35 years), with mean minimum and maximum air temperatures varying between

7°C – 15°C and 18°C – 25°C, respectively (Agronet Weather Data Basis 2002). The monthly average maximum temperature, the monthly rainfall, monthly long-term rainfall and monthly evapotranspiration for the study period are shown in Table 3.1. Most of the rainfall (75%) occurred between June 2008 and November 2009 during the study period. The distribution of the rainfall shows extended periods of under average rainfall (September and October 2008) followed by very high rainfall (November 2008).

Table 3.1 Monthly average maximum temperature (ºC), monthly rainfall (mm) and monthly evapotranspiration (mm) for the trial period (June 2008 – April 2009), as well as monthly long-term rainfall (mm) (mean for 30 years).

Month	Average maximum temperature	Monthly rainfall	Monthly evapotranspiration	Long term monthly rainfall
Jun '08	19	83	51	40
Jul	19	17	63	43
Aug	19	68	76	58
Sep	19	25	104	56
Oct	20	41	121	79
Nov	21	194	102	69
Dec	23	3	111	67
Jan '09	24	14	115	63
Feb	25	64	100	56
Mar	26	12	125	72
Apr	24	54	112	71
Total	N/A	575	N/A	674

3.3 SOIL

The soil in the study area (the farm as whole) is mostly of the Escourt form (Lammermoor family; KA 1000) (Soil Classification Working Group 1991). Clay content increases with soil depth from 20% in the A horizon (0 – 250 mm) to 40% in the B horizon (450 – 700 mm) (Soil Classification Working Group 1991).

3.4 DAIRY PASTORAL SYSTEMS (DPS)

3.4.1 Project layout

Approximately nine hectares (ha) of existing irrigated *Pennesitum clandestinum* (kikuyu) was divided into eight blocks that acted as replicates. Each block was divided into three experimental paddocks to which three different pasture treatments were randomly allocated, the so-called dairy pastoral systems. Therefore, there were a total of 24 experimental paddocks, with eight paddocks allocated to each treatment. Each experimental paddock was divided into two grazing strips (with identical pasture treatments). Three of the eight blocks was referred to as monitor camps on which all pasture measurements were done. The sizes of the paddocks ranged from 0.340 ha to 0.406 ha.

3.4.2 Dairy Pasture Treatments (DPT)

For the first dairy pastoral treatment (DPT I), *L. multiflorum* variety italicum was planted into mulched *P. clandestinum* at 25 kg ha^{-1} using an Aitchison seeder, during March 2008. For the second dairy pastoral treatment (DPT II) *L. multiflorum* variety westerwoldicum was over-sown into *P. clandestinum* at 25 kg ha^{-1} during March 2008, using a mulcher (1.6 meter Nobili with 24 blades). *Lolium perenne* was planted at 20 kg ha^{-1} into mulched *P. clandestinum* using an Aitchison seeder, during April 2008 for the third dairy pastoral treatment (DPT III). *Pennesitum clandestinum* was grazed to a height of 50 mm prior to the commencement of planting. The different cultivars, scientific names, seeding densities and over-sowing methods used in the three different dairy pastoral treatments are summarized in Table 3.2.

Table 3.2 Ryegrass treatments, cultivars, scientific names, seeding densities (kg ha^{-1}) and over-sowing methods used in the three dairy pastoral systems (DPT I, DPT II, DPT III).

DPT	Treatment	Scientific name	Cultivars	Seeding density	Over-sowing method
I	Italian ryegrass	*L. multiflorum* var. italicum	Jeanne	25	Graze to 50 mm Mulcher Seeder Land roller
II	Westerwolds ryegrass	*L. multiflorum* var. westerworldicum	Jivet	25	Graze to 50 mm Broadcast seed Mulcher Land roller
III	Perennial ryegrass	*L. perenne*	Bronsyn	20	Graze to 50 mm Mulcher Seeder Land roller

3.4.3 Irrigation

Irrigation was done by means of a permanent overhead sprinkler system, which was scheduled by means of tensiometers. Tensiometers were strategically placed throughout the study area at a depth of 150 mm (Botha 2002) to ensure sufficient irrigation for all experimental paddocks. Irrigations commenced at a tensiometer reading of –25 Kpa and were terminated at a reading of –10 Kpa (Botha 2002).

3.4.4 Fertilizer

Fertilizer was applied to raise the soil phosphorus level to 35 mg kg^{-1}, potash level to 80 mg kg^{-1} and the pH (KCl) to 5.5. The treatments were top dressed monthly with nitrogen at 55 kg N ha^{-1} (Botha 2009).

3.4.5 Experimental animals

Jersey cows strip-grazed each grazing strip (Figure 3.2) for two days and each experimental paddock for four days, resulting in a 32 day grazing cycle. Camps were grazed according to a put-and-take system, which consists of adding additional cows to groups when the pasture production exceeds demand and removing cows when pasture demands exceeds production.

Figure 3.2 Jersey cows grazing on an experimental paddock.

3.5 BEEF PASTORAL SYSTEMS (BPS)

3.5.1 Project layout

Approximately 24 hectares (ha) of existing non-irrigated *P. clandestinum/ Eragrostis plana* (taaipol) pastures were divided into six blocks that acted as replicates. Each block was divided into four experimental paddocks to which four pasture treatments were randomly allocated, the so-called beef pastoral systems. The size of the paddocks ranged from 0.955 ha to 1.15 ha. In total there were 24 experimental paddocks, with six paddocks allocated for each treatment. Three of the six blocks were referred to as monitor camps, on which all pasture measurements were done.

3.5.2 Beef Pasture Treatments (BPT)

The different cultivars, scientific names, seeding densities and over-sowing methods used in the four different beef pastoral treatments are summarized in Table 3.3.

Table 3.3 Treatments, cultivars, scientific names, seeding densities (kg ha^{-1}) and over-sowing methods used in the four beef pastoral systems (BPT I, BPT II, BPT III, BPT IV).

BPT	Treatment	Scientific name	Cultivars	Seeding density	Over-sowing method
I	Annual ryegrass	*L. multiflorum*	Energa	15	Broadcast seed
	Rescue grass	*B. catharticus*	Matoa	20	Land roller
	Trefoil	*L. corniculatus*	San Gabriël	4	
II	Annual ryegrass	*L. multiflorum*	Energa	15	Broadcast seed
	Rescue grass	*B. catharticus*	Matoa	20	Mulcher
	Trefoil	*L. corniculatus*	San Gabriël	4	Land roller
III	Perennial ryegrass	*L. perenne*	Bronsyn	5	Mulcher
	Cocksfoot	*D. glomerata*	Cambria	5	Planter
	Fescue	*F. arundinaceae*	Fuego	5	Land roller
	White clover	*T. repens*	Haifa	5	
IV	Fescue	*F. arundinaceae*	Fuego	20	Spray herbicide
					Planter
					Land roller

Beef pastoral treatment one (BPT I) and two (BPT II) consisted of *L. multiflorum* variety westerwoldicum cultivar Energa, *Bromus catharticu*s cultivar Matoa (rescue grass) and *Lotus corniculatus* cultivar San Gabriël (trefoil) over-sown into *P. clandestinum*/*E. plana* pastures at 15 kg ha^{-1}, 20 kg ha^{-1}, 4 kg ha^{-1}, respectively, during May 2008. The third beef pastoral treatment (BPT III), consisted of *L. perenne* cultivar Bronsyn, *Dactylis glomerata* cultivar Cambria (cocksfoot), *Festuca arundinaceae* cultivar Fuego (fescue) and *Trifolium repens* cultivar Haifa (white clover) planted at 5 kg ha^{-1} each, during May 2008 with a mulcher-planter combination. The fourth beef pastoral treatment (BPT IV) consisted of *F. arundinaceae* planted into *P. clandestinum*/*E. plana* pastures at 20 kg ha^{-1}, during May 2008 (Botha *et al*. 2009).

3.5.3 Fertilizer

Lime was applied to previously worked lands at a rate of up to 2 tons/ha. Thereafter, fertilizer was applied to raise the soil levels, the same as that are explained for the dairy pastoral systems, namely phosphorus level to 35 mg kg^{-1}, potash level to 80 mg kg^{-1} and the pH (KCl) to 5.5. The treatments were top dressed four times a year with nitrogen at 50 kg N ha^{-1}.

3.5.4 Experimental animals

Nguni x Jersey crossbred oxen and heifers grazed (Figure 3.3) for seven days on each experimental paddock, resulting in a 42 day grazing cycle. Camps were grazed according to a put-and-take system. The number of animals per paddock was adjusted weekly to ensure a forage availability of 3% of their bodyweight per day. When pasture supply was higher than pasture demand, additional Jersey heifers, with a comparable live weight were added to the experimental groups.

Figure 3.3 Nguni x Jersey oxen and heifers grazing on an experimental paddock.

3.6 EXPERIMENTAL PROCEDURES

Vegetation sampling took place one day prior to cattle entering the experimental paddocks. For the three dairy and four beef pastoral treatments, sampling on the monitor camps, took place on the same sampling dates, respectively. The beef and dairy pastoral systems were sampled on 18 and 28 dates, respectively, between June 2008 and April 2009.

3.6.1 Destructive herbage biomass estimation

Vegetation clipping in quadrangular quadrats (0.50 x 0.50 m / 0.25 m^2) ('t Mannetjie 2000) was used to determine the "true/actual" amount of herbage biomass for each of the beef and dairy monitoring camps. In each monitor camp the locations for measurement was selected at random to be representative of the vegetation sampled. There were 17 and 11 quadrats cut per monitor camp for the different beef and dairy pastoral treatments, respectively. The amount of quadrates clipped was chosen suitable to labor and time available. The vegetation in each quadrat was clipped to height of 30 mm aboveground level with hand-held shears. Each quadrat was equipped with so-called legs (30 mm) to ensure the correct cutting height (‘t Mannetjie 2000).

The total fresh weight for each quadrat was recorded to the nearest gram, after which five reference quadrates of the total amount of quadrats was dried at 60°C (1 400 L SWC forced convention oven) for at least 72 hours (van Heerden & Tainton 1987). Dried samples were weighed to the nearest gram and used in the regression analysis for each of the herbage biomass estimation methods.

The remaining cut quadrat samples, twelve and six for beef and dairy pastoral treatments, respectively, were pooled and mixed thoroughly. From this pooled sample, three sub-samples were taken, weighed wet and dried. Dried sub-samples were weighed to the nearest gram to determine dry matter (kg DM) within the 0.25 m^2 area at a specific height. Information regarding these pooled sub-samples was used to calculate the amount of dry matter per hectare (kg DM ha^{-1}) for each of the sampled monitor camps within both the different beef and dairy pastoral systems. Thus, herbage biomass (kgDM/ha) for each of the DPT and BPT, was estimated on each sampling occasion from the mean herbage biomass per sampled quadrat (kgDM/quadrate).

A fourth sub sample was taken from the pooled sampling for determination of the “true/actual” botanical composition of each monitor camp (see section 3.5.3 Destructive botanical composition estimation).

3.6.2 Non-destructive herbage biomass estimations

All non-destructively herbage biomass estimation measurements for each monitor camp, for both the beef and dairy pastoral systems, were done within the sampled quadrats used for the “true/actual” herbage biomass estimation (see section 3.6.1 Destructive herbage biomass estimation). All measurements were made in order from least to most destructive to minimize errors that could occur from manipulating the vegetation within the quadrat area. All measurements during the study period were done by a single observer to minimize variation (Earle & McGowan 1979; Aiken & Bransby 1992). At each sampled quadrat, herbage biomass measurements was taken by using the rising plate meter, the comparative yield method and the meter stick. These procedures will be discussed in detail.

3.6.2.1 Rising plate meter

Forage density in each treatment was measured using the Ellinbank rising plate meter (Stockdale 1984b; Fulkerson 1997). The rising plate meter consists of a shaft and a circular metal plate with an area of 0.098 m^2 and an overall mass of 1.014 kg. A single measurement of compressed sward height using the rising plate meter was taken at the center of each quadrat. For each measurement the shaft were held vertically (each time from the same height) and placed on the grass. After the plate settled the distance between the plate and the soil surface, a measure of the height of the vegetation, was read of the marked part of the shaft.

For regression analysis the five reference quadrats were clipped (see section 3.6.1 Destructive herbage biomass estimation). A calibration equation was obtained from these data by developing a linear regression between the rising plate meter readings and herbage dry matter (DM) mass. The calibration equation namely $y = mx + b$ was used for predicting pasture mass, where y = yield (kg DM ha^{-1}), m = factor (gradient), x = height and b = constant. Herbage biomass for each monitor camp was estimated by using the average rising plate meter reading per paddock (readings taken in each of the 11 or 17 quadrates) and the corresponding regressions for each specific paddock.

3.6.2.2 Comparative yield method

Herbage biomass in each treatment was visually estimated using the comparative yield method (Haydock & Shaw 1975). Five reference quadrats were selected to represent the range of weights likely to be encountered at each monitor camp, ranging from standard 1 to standard 5. Standard 1 represented the least and standard 5 the largest amount of herbage biomass present on each monitor camp.

At each quadrat placement during sampling, the quadrat was mentally compared to the standards and given a corresponding ranking to the appropriate standard. If herbage biomass of a quadrat appeared to be between two standards, a half score ranking was given. In an event where a quadrat was encountered in which herbage biomass greatly exceeded the herbage biomass of standard 5, a higher ranking was estimated (Haydock & Shaw 1975).

For regression analysis the five reference quadrats were clipped (see section 3.6.1 Destructive herbage biomass estimation). A calibration equation was obtained from these data by developing a linear regression between ranking and herbage DM mass. The calibration equation namely $y = mx + b$ was used for predicting pasture mass, where y = yield (kg DM ha^{-1}), m = factor, x = ranking and b = constant. Herbage biomass for each monitor camp was estimated by using the average ranking per paddock (readings taken from the 11 or 17 quadrates) and the corresponding regressions for each specific paddock.

3.6.2.3 Meter stick

Sward height in each treatment was measured using a stick on which divisions in centimeters was marked. Canopy height for each quadrat was estimated by measuring the tallest part of the herbage that touched the meter stick at each of the four corners and in the middle of the quadrat. In total five height measurements were taken in each quadrat. A mean value from the five measurements represented the value for each sampled quadrat. Measurements were taken as the natural undisturbed height of the plants adjacent to the meter stick, not stretched or extended (Martin *et al*. 2005) with both bare spots and dense spots recorded.

For regression analysis the five reference quadrats were clipped (see section 3.6.1 Destructive herbage biomass estimation). A calibration equation was obtained from these data by developing a linear regression between the meter stick and herbage DM mass. The calibration equation namely y = mx + b was used for predicting pasture mass, where y = yield (kg DM ha^{-1}), m = factor, x = height and b = constant. Herbage biomass for each monitor camp was estimated by using the average meter stick reading per paddock (readings taken from the 11 or 17 quadrates) and the corresponding regressions for each specific paddock.

3.6.3 Destructive botanical composition estimation

The same quadrats were used, as for the determination of "true/actual" herbage biomass (see section 3.6.1 Destructive herbage biomass estimation). A fourth sub-sample of the cut material, weighing more than 500 g wet, was taken from the pooled sample. The entire sub-sample was hand separated into individual species. Dairy pastoral treatment I, II and III was hand separated into ryegrass, *P. clandestinum* and other species (rest of species). Beef pastoral treatment II and I were separated into *E. plana*, *P. clandestinum*, ryegrass, *B. catharticus*, *L. corniculatus* and other species. Beef pastoral treatment III were separated into *E. plana*, *P. clandestinum*, ryegrass, *D. glomerata*, *F. arundinaceae, T. repens* and other species, while the sub-sample from beef pastoral treatment IV were separated into *E. plana*, *P. clandestinum*, *F. arundinaceae* and other species (rest of species).

Plant material of each species was dried before being weighed to the nearest gram. Percentage of species composition for each grab sample was calculated to represent the percentage species composition for each sampled monitor camp for both the beef and dairy pastoral treatments.

3.6.4 Non-destructive botanical composition estimation (Dry-weight-rank method)

All non-destructively botanical composition estimation measurements for each monitor camp, for both the beef and dairy pastoral systems, were made within the sampled quadrats used for the "true/actual" herbage biomass estimation (see 3.6.1 destructive herbage biomass estimation). At each sampled quadrat, botanical composition measurements were taken using the dry-weight-rank method.

Each sampled quadrat was ranked by the dry-weight-rank method ('t Mannetjie & Haydock 1963) to determine species composition within each quadrat**.** The three most abundant species in each quadrat were given a ranking of one, two or three, where one indicated the most abundant species. If only one species was present, all three species ranks were given to that particular species. If one species contributed more than 85% of the standing herbage biomass in a quadrat, that species was given both rank one and two and the second most abundant species were given rank three (Jones & Hargreaves 1979).

Rankings were converted to dry weight species composition by multiplying the proportion of occurrences of each ranking for species by multipliers of 0.70, 0.21 and 0.09 for first, second and third ranked species, respectively ('t Mannetjie & Haydock 1963).

3.7 STATISTICAL ANALYSIS OF ESTIMATION METHODS

A calibration equation was obtained from data collected by developing a linear regression between the rising plate meter, the comparative yield method and the meter stick and herbage dry matter mass. The calibration equation namely $y = mx + b$ was used for predicting pasture mass, where y = yield (kg DM ha^{-1}), m = factor, x = height and b = constant. Herbage biomass for each monitor camp was estimated by using the average rising plate meter reading, meter stick reading and comparative yield ranking per paddock (readings taken from the 11 quadrats in the DPT or from the 17 quadrats in the BPT during sampling) and the corresponding regressions for each specific paddock.

Thereafter, linear regression analysis was applied to identify which of the four non-destructive herbage biomass/botanical composition estimation methods (rising plate meter, comparative yield method, meter stick, dry-weight-rank method) best estimated the destructive herbage biomass/botanical composition estimation method. The model fitted was $y = a + bx$, where 'y' is one of the four estimation methods (rising plate meter, comparative yield method, meter stick, dry-weight-rank method), 'x' the destructive herbage biomass/botanical composition estimation method, 'a' an estimate of the constant regression parameter and 'b' the slope parameter or unit of change. The accuracy of the different methods for estimating herbage biomass was compared using the coefficient of determination (r^2) values between cut quadrats and the herbage biomass estimates for the three different non-destructive herbage biomass estimation methods by assuming best model fit = highest r^2, intercept closest to 0; slope closest to 1 and with the smallest standard error values was defined to be the model that best predicted actual herbage biomass (Draper & Smith 1981).

The actual percentages of the dry-weight composition and their corresponding estimates were generated from the same data subsets. A paired t-test was used to test the hypothesis of no difference between the estimated and actual percentages of dry weight composition of each species.

Furthermore, factorial analysis of variance (ANOVA) for a randomised complete block design (RCBD) and unbalanced data was applied to test for differences between treatments, seasons and the treatment by season interaction on the destructive herbage biomass/botanical composition estimation method. The two seasons were defined as winter to spring and summer to autumn, where winter to spring = June, July, August, September, October, November and summer to autumn = December, January, February, March, April. There were three blocks that served as replicates.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 DAIRY PASTORAL SYSTEMS

4.1.1 Destructive herbage biomass estimates

The mean “true/actual” herbage biomass determined through vegetation clipping for each of the dairy monitoring camps, are presented in Table 4.1 for the three dairy pastoral treatments. For dairy pastoral treatment one, the lowest (P<0.05) and the highest (P<0.05) mean seasonal herbage biomass were estimated during winter/spring and summer/autumn, respectively. Herbage biomass estimated for DPT III and DPT II were not significantly (P>0.05) different between the winter/spring and summer/autumn seasons.

Table 4.1 Mean (±SE) seasonal “true/actual” herbage biomass (kg DM ha^{-1}) estimated for the three dairy pastoral treatments (DPT I, DPT II and DPT III) for the winter/spring and summer/autumn seasons. Where winter/spring = June, July, August, September, October, November and summer/autumn = December, January, February, March, April. Measurements took place between June 2008 and April 2009. Herbage biomass means (n = 3) within a line or column for a season or treatment, respectively, with no common superscript letters indicate significant (P<0.05) differences. *LSD (0.05) compares herbage biomass over treatments within season. **LSD (0.05) compares herbage biomass over seasons within treatment. LSD = Least significant difference

DPT	**I**	**II**	**III**	***LSD (0.05)**
Winter/spring	1576^{a}	1457^{a}	1828^{a}	
	± 5.72	± 5.28	± 5.39	**392.97**
Summer/autumn	1972^{b}	2473^{a}	2202^{ab}	
	± 5.32	± 7.29	± 5.15	**470.33**
****LSD (0.05)**	**163.85**	**1119.50**	**382.37**	

During winter/spring, the mean seasonal herbage biomass did not differ significantly (P>0.05) between any of the three dairy pastoral treatments. However, during summer/autumn, herbage biomass estimated for DPT I was significantly lower (P<0.05) than that of the mean seasonal herbage biomass estimated for DPT II. The seasonal herbage biomasses estimated during summer/autumn did not differ significantly (P>0.05) between DPT II and DPT III.

4.1.2 Destructive botanical composition estimates

The "true/actual" botanical composition determined through clipping and hand separating of the vegetation into individual species for each of the dairy monitoring camps, are presented in Table 4.2 for the three dairy pastoral treatments. In terms of management the reason for planting different ryegrass species into *Pennisetum clandestinum* pastures during autumn were to provide the animals with adequate fodder of high quality during winter/spring when the production of *P. clandestinum* is known to be low (Botha 2009a). *Lolium multiflorum* variety italicum, *Lolium multiflorum* variety westerworldicum and *Lolium perenne* was used for DPT I, DPT II and DPT III, respectively. When different ryegrass species are planted into *P. clandestinum* pastures, inter species competition can be expected (Botha 2009).

The dairy pastoral treatments consisted predominantly of ryegrass and *P. clandestinum* during the winter/spring and summer/autumn seasons, respectively. From winter/spring to summer/autumn the average percentage *P. clandestinum* increased (P<0.05) significantly, whereas in the case of ryegrass it significantly decreased (P<0.05) for all three of the dairy pastoral treatments.

As a percentage of the whole botanical composition, during winter/spring time the *P. clandestinum* and ryegrass component between DPT III and I did not differ (P>0.05) much from each other. Dairy pastoral treatment two had the highest (P<0.05) percentage *P. clandestinum* and the lowest (P<0.05) ryegrass component as estimated during winter/spring. The mean percentage "other" species during winter/spring, were significantly lower ($P<0.05$) for DPT I, than for DPT III and II. The "other" species consisted of *Paspallum notatum* (Bahia grass), *Trifolium repens*, *Eragrostis plana* and *Bromus catharticus*.

Table 4.2 Mean (±SE) seasonal "true/actual" botanical compositions (%) (species) estimated for the three dairy pastoral treatments (DPT I, DPT II and DPT III) for the winter/spring and summer/autumn seasons between June 2008 and April 2009. Species means (n = 3) within a block for species and seasons with no common superscript letters indicate significant ($P<0.05$) differences. LSD (0.05) compares individual species over seasons and treatments.

Species	**Season**	**DPT I**	**DPT II**	**DPT III**	**LSD (0.05)**
P. clandestinum	Winter/spring	7^{e}	15^{d}	3^{e}	
		± 1.41	± 0.92	± 2.00	
	Summer/autumn	54^{b}	68^{a}	31^{c}	
		± 1.99	± 1.19	± 2.01	**6.73**
Ryegrass	Winter/spring	86^{a}	70^{bc}	78^{ab}	
		± 1.37	± 2.16	± 2.49	
	Summer/autumn	33^{d}	10^{e}	54^{c}	
		± 2.04	± 2.05	± 2.01	**14.64**
Other	Winter/spring	7^{c}	15^{ab}	19^{ab}	
		± 1.50	± 2.22	± 2.12	
	Summer/autumn	13^{bc}	22^{a}	15^{ab}	
		± 1.39	± 2.09	± 0.79	**8.59**

During summer/autumn, the highest ($P<0.05$) and lowest ($P<0.05$) percentage *P. clandestinum* was estimated for DPT II and DPT III, respectively, whereas the percentage ryegrass was significantly lower ($P<0.05$) for DPT II than for DPT III. Thus, the mean seasonal percentage ryegrass remained high in DPT III during summer/autumn, relative to that of ryegrass estimated for DPT II. Dairy pastoral treatment two appears to favour the growth of the *P. clandestinum* component during summer/autumn, whereas DPT III seems to favour the growth of the ryegrass component. Dairy pastoral treatment two had the highest ($P<0.05$) percentage "other" species estimated during summer/autumn.

4.1.3 Comparison of non-destructive methods to determine herbage biomass

The non-destructively herbage biomasses determined with the rising plate meter, the comparative yield method and the meter stick were compared to the "true/actual" values estimated with the destructive method as presented in Table 4.1. The relationship between cut quadrats and the herbage biomass estimated for the non-destructive methods for DPT I, DPT II and DPT III, as well as over seasons, are shown in Tables 4.3 and 4.4, respectively. Scatter plots of the "true/actual herbage biomasses versus herbage biomass estimated by the three non-destructive methods are also presented in Appendix 1 (Figures 1 – 9).

The accuracy of the different methods for estimating herbage biomass was compared using the coefficient of determination (r^2) values between cut quadrats and the herbage biomass estimates for the three different non-destructive herbage biomass estimation methods by assuming best model fit = highest r^2, intercept closest to 0; slope closest to 1 and with the smallest standard error values was defined to be the model that best predicted actual herbage biomass (Draper & Smith 1981). Hand clipping values and herbage biomass estimates were positively correlated ($P<0.05$) for all three non-destructive methods (Appendix 2, Table 1).

For dairy pastoral treatment one the coefficient of determination varies between 0.73 and 0.79 for the non-destructive methods (Table 4.3). The meter stick resulted in the standard error values closest to 0. For dairy pastoral treatment one, the meter stick resulted in the over all best model fit for predicting herbage biomass.

Table 4.3 Coefficient of determination (r^2), intercept, standard error of the intercept (SE^I), slope and standard error of the slope (SE^s) values, between cut quadrats and herbage biomass (kg DM ha^{-1}) estimates for the non-destructive methods for DPT I, II and III. Measurements took place between June 2008 and April 2009. Note: The model with highest r^2, intercept closest to 0; slope closest to 1 and with the smallest standard error values was defined to be the model that best predicted actual herbage biomass (Draper & Smith 1981).

		Non-destructive methods		
DPT		**Rising plate**	**Comparative yield**	**Meter stick**
I	r^2	0.73	0.75	0.79
	r	0.85 *	0.86 *	0.88 *
	Intercept	66.59	-3.03	141.55
	SE^I	203.81	198.62	162.19
	Slope	1.02	1.08	0.97
	SE^S	0.12	0.12	0.10
II	r^2	0.85	0.86	0.85
	r	0.92 *	0.93 *	0.92 *
	Intercept	162.63	166.76	349.78
	SE^I	145	138.16	131.53
	Slope	0.88	0.93	0.77
	SE^S	0.07	0.07	0.06
III	r^2	0.69	0.72	0.81
	r	0.83 *	0.85 *	0.90 *
	Intercept	402.09	419.55	336.04
	SE^I	206.08	189.66	156.19
	Slope	0.85	0.87	0.91
	SE^S	0.11	0.11	0.09

* Significant at $P<0.05$

For dairy pastoral treatment two the rising plate meter (r^2 = 0.85), the comparative yield method (r^2 = 0.86) and the meter stick (r^2 = 0.85) resulted in, not only the highest but also in more closely similar coefficient of determination values (Table 4.3). The meter stick gave the standard error values closest to 0, whereas the rising plate meter the intercept value closest to 0. The comparative yield method showed the slope value closest to 1. For dairy pastoral treatment two, the linear relationship between "true/actual" herbage biomass and herbage biomass estimates for all three non-destructive methods were closely similar.

For dairy pastoral treatment three the meter stick resulted in the highest r^2 value, the lowest intercept value, SE values closest to 0 and the slope value closest to 1 (Table 4.3). The meter stick resulted in the strongest linear relationship between cut quadrats and estimated herbage biomass for DPT III, as with DPT I .

Therefore, by using linear equations, herbage biomass determinations could be made with all three non-destructive methods. The study indicated that in the dairy pastoral systems the meter stick (r^2 = 0.79 – 0.85) provided the overall highest r^2 values, followed by the comparative yield method (r^2 = 0.72 – 0.86) and the rising plate meter (r^2 = 0.69 – 0.85). Martin *et al*. (2005) also concluded that the meter stick was more effective in estimating herbage biomass than the rising plate meter and the visual estimation method in dairy pastures.

Alexander *et al*. (1962) took a mean of several readings to estimated canopy height on quadrats and had varying levels of success when predicting herbage biomass with separate models for individual trials (r^2 = 0.60 to 0.92). Griggs and Stringer (1988) reported coefficients of determination ranging from 0.59 to 0.86 where canopy height was measured to the nearest mm with a meter stick that had a sliding 1 m crossbar that could be lowered to measure the mean canopy height. For both plot and pasture biomass estimation, Gonzalez *et al*. (1990) reported a coefficient of determination of 0.86 using mean height, while Harmoney *et al*. (1997) found that canopy height poorly explained the variation of the biomass they sampled (r^2 = 0.55) when measuring the height of the tallest leaf tissue present within their frame to the nearest 20 mm. Therefore, caution should be taken when comparing results or applying models from study to study because of the observer variability

(Aiken & Bransby 1992), different instruments used and different methods of comparing meter readings to clipped estimates of herbage biomass.

Furthermore, it must be considered that for the meter stick, five measurements were taken to represent the 0.25 m^2 area, while for the rising plate meter and the comparative yield method only one measurement was taken to cover the whole area. In most studies reported in the literature, only one rising plate and/or comparative yield method measurement is taken, while several meter stick heights are recorded and averaged. Virkajärvi (1999) took one rising plate meter reading and three sward stick height measurements in each 0.90 m^2 area, and found that both methods were equally effective for predicting herbage biomass. Fulkerson & Slack (1993) and Martin *et al*. (2005) reported that the accuracy of the meter stick could be improved by investing more time in recording additional height measurements per sampled area.

Table 4.4 Coefficient of determination (r^2) values between cut quadrats and herbage biomass (kg DM ha^{-1}) estimates for the non-destructive methods for DPT I, II and III for winter/spring and summer/autumn between June 2008 and April 2009. Note: Best model fit = highest r^2 (Draper & Smith 1981).

		Non-destructive methods		
DPT	**Seasons**	**Rising plate**	**Comparative yield**	**Meter stick**
I	Winter/spring	0.73	0.80	0.86
	Summer/autumn	0.69	0.60	0.64
II	Winter/spring	0.75	0.88	0.80
	Summer/autumn	0.64	0.59	0.59
III	Winter/spring	0.79	0.72	0.80
	Summer/autumn	0.56	0.67	0.73

As found by Phillips & Clark (1971) and Earle & McGowan (1979) the accuracy of the non-destructive methods varied considerably between seasons (Table 4.4). This is attributed to the difference in dry matter percentages and the difference in species composition in the same sward between seasons.

The coefficient of determination values between cut quadrats and herbage biomass estimates, for all three non-destructive herbage biomass estimation methods, decreased from winter/spring to summer/autumn time for all three dairy pastoral treatments. During winter/spring the meter stick resulted in the highest r^2 value for DPT I and DPT III and the comparative yield method for DPT II. During summer/autumn the rising plate meter resulted in the highest r^2 value for DPT II and I, whereas the meter stick resulted in the highest r^2 value for DPT III. As supported Martin *et al*. (2005) it can be concluded that the species composition of the different dairy pastoral treatments had a definitely affect on the accuracy of the non-destructive herbage biomass estimation methods.

4.1.4 Evaluation of the dry-weight-rank method for botanical analysis

The "true/actual" botanical composition determined through cutting and that estimated by the dry-weight rank method (non-destructively) are shown in Table 4.5. The species composition (*P. clandestinum*/ryegrass) estimates from the dry-weight-rank method and hand clippings did not differ significantly ($P>0.05$) for DPT I and DPT II. For dairy pastoral treatment three, the dry-weight-rank method and hand clippings also resulted in small differences ($P>0.05$) in estimates for the percentage ryegrass for winter/spring and summer/autumn. However, the dry-weight-rank method over-estimated ($P<0.05$) the percentage *P. clandestinum* in the whole botanical composition during winter/spring with 2%.

The results indicate that the dry-weight-rank method of botanical composition analysis is an accurate means of estimating botanical composition of cultivated dairy pastoral systems. Studies from 't Mannetjie Haydock (1963), Jones & Hargreaves (1979) and Friedel *et al*. (1988) also shown that the botanical composition estimates through the dry-weight-rank method do not significantly differ from hand clipped values. In this study, the contribution of 92% of all species within the dairy pastoral systems was estimated within 5% accuracy of the "true/actual" value of species hand clipped.

Table 4.5 Botanical compositions (%) (species) determined by hand clipping (clip) and the dry-weight-rank (DWR) method on the three dairy pastoral treatments (DPT I, II and III) for winter/spring and summer/autumn. Measurements took place between June 2008 and April 2009. Differences between means (n = 3) within a line for a species with P<0.05 indicate that differences significantly deviated from zero. LSD (0.05) compares between clip and DWR values for individual species within treatments.

DPT	Species	Season	Clip	DWR	LSD
I	*P. clandestinum*	Winter/Spring	7[a]	11[a]	**4.78**
		Summer/Autumn	54[a]	49[a]	**8.84**
	Ryegrass	Winter/Spring	86[a]	85[a]	**6.59**
		Summer/Autumn	33[a]	34[a]	**8.87**
II	*P. clandestinum*	Winter/Spring	15[a]	20[a]	**6.24**
		Summer/Autumn	68[a]	76[a]	**10.43**
	Ryegrass	Winter/Spring	70[a]	66[a]	**8.39**
		Summer/Autumn	10[a]	6[a]	**6.38**
III	*P. clandestinum*	Winter/Spring	3[b]	5[a]	**2.35**
		Summer/Autumn	31[a]	36[a]	**6.36**
	Ryegrass	Winter/Spring	78[a]	79[a]	**5.56**
		Summer/Autumn	54[a]	56[a]	**5.46**

4.2 BEEF PASTORAL SYSTEMS (BPS)

4.2.1 Destructive herbage biomass estimates

The means seasonal “true/actual” herbage biomass determined through clipping of the vegetation in quadrangular quadrats for each of the beef monitoring camps are presented for the four beef pastoral treatments in Table 4.6. The mean seasonal herbage biomass did not differ significantly (P>0.05) between seasons for all four beef pastoral treatments.

Table 4.6 Mean (±SE) seasonal “true/actual” herbage biomass (kg DM ha^{-1}) estimated for the four beef pastoral treatments (BPT I, II, III and IV) for winter/spring and summer/autumn. Measured between June 2008 and April 2009. Means (n = 3) within a line or column for a season and treatment, respectively, with no common superscript indicate significant (P<0.05) differences. *LSD (0.05) compares herbage biomass over treatments within season. **LSD (0.05) compares herbage biomass over seasons within treatment.

BPT	**I**	**II**	**III**	**IV**	***LSD (0.05)**
Winter/spring	2026^{a}	1382^{ab}	1236^{b}	1568^{ab}	
	± 9.05	± 8.52	± 7.68	± 3.88	**693.46**
Summer/autumn	2032^{a}	1710^{ab}	1461^{b}	1463^{b}	
	± 8.98	± 8.22	± 8.57	± 8.02	**558.97**
****LSD (0.05)**	**2686.80 *** **	**1763.10**	**941.72**	**1138.3**	

*** LSD high, due to high variability between monitoring camps

During winter/spring and summer/autumn time, herbage biomass estimated for BPT I were, significantly higher (P<0.05) than for BPT III. Furthermore, the mean seasonal herbage biomass estimated for BPT IV were also lower (P<0.05) than the herbage biomass estimated for BPT I, during summer/autumn.

4.2.2 Destructive botanical composition estimates

The mean seasonal “true/actual” botanical composition estimated for the four beef pastoral treatments during the study period are shown in Table 4.7. In terms of management different grass and legume species were planted in *P. clandestinum*/*E. plana* pastures during May in an attempt to increase seasonal production and carrying capacity of a pasture production unit (Botha 2009). The different beef pastoral treatments and season had a definitely influence on the presence of the different species planted as a pasture mixture into *P. clandestinum*/*E. plana* pastures.

Table 4.7 Mean (±SE) seasonal "true/actual" botanical compositions (%) (species) estimated for the four beef pastoral treatments (BPT I, II, III and IV) one (BPT I) for winter/spring and summer/autumn between June 2008 and April 2009. Means (n = 3) within a block for species and seasons with no common superscript indicate significant (P<0.05) differences. LSD (0.05) compares individual species over seasons and treatments.

Species	**Season**	**BPT I**	**BPT II**	**BPT III**	**BPT IV**	**LSD (0.05)**
P. clandestinum	Winter/spring	$46^{ab} \pm 3.38$	$19^{c} \pm 2.60$	$35^{bc} \pm 1.26$	$28^{c} \pm 2.68$	
	Summer/autumn	$56^{a} \pm 3.57$	$33^{c} \pm 2.44$	$53^{a} \pm 2.47$	$57^{a} \pm 2.91$	**16.02**
E. plana	Winter/spring	$27^{ab} \pm 3.24$	$25^{ab} \pm 2.34$	$19^{ab} \pm 2.50$	$4^{c} \pm 2.55$	
	Summer/autumn	$33^{a} \pm 3.68$	$32^{a} \pm 2.56$	$27^{ab} \pm 2.73$	$4^{c} \pm 1.98$	**13.04**
Ryegrass	Winter/spring	$13^{bc} \pm 1.32$	$36^{a} \pm 1.81$	$18^{b} \pm 1.94$	*	
	Summer/autumn	$2^{d} \pm 1.11$	$7^{cd} \pm 1.80$	$2^{d} \pm 0.82$	*	**6.61**
B. catharticus	Winter/spring	$5^{ab} \pm 1.41$	$8^{a} \pm 1.87$	*	*	
	Summer/autumn	$1^{b} \pm 0.72$	$1^{b} \pm 0.83$	*	*	**7.48**
L. corniculatus	Winter/spring	$4^{b} \pm 1.78$	$6^{ab} \pm 1.34$	*	*	
	Summer/autumn	$5^{b} \pm 1.72$	$10^{a} \pm 1.73$	*	*	**4.37**
D. glomerata	Winter/spring	*	*	$13^{a} \pm 1.82$	*	
	Summer/autumn	*	*	$10^{a} \pm 2.13$	*	**11.52**
F. arundinaceae	Winter/spring	*	*	2^{b}	27^{a}	
	Summer/autumn	*	*	2^{b}	27^{a}	**14.54**
T. repens	Winter/spring	*	*	$2^{a} \pm 1.27$	*	
	Summer/autumn	*	*	$0^{a} \pm 0.45$	*	**4.92**
Other	Winter/spring	$5^{c} \pm 1.70$	$9^{c} \pm 1.31$	$11^{bc} \pm 1.70$	$41^{a} \pm 2.49$	
	Summer/autumn	$4^{c} \pm 1.11$	$17^{b} \pm 1.81$	$6^{c} \pm 1.58$	$12^{bc} \pm 1.51$	**10.41**

Beef pastoral treatment one and two consisted of *P. clandestinum*, *E. plana*, ryegrass, *B. catharticus*, *Lotus corniculatus* and "other" species. Vegetation on BPT III consisted of *P. clandestinum*, *E. plana*, *Festuca arundinaceae* and "other" species, whereas BPT IV consisted of *P. clandestinum*, *E. plana*, *F. arundinaceae* and "other" species. The "other" species consisted of *Stellaria meadia* (Chickweed), *Paspallum notatum*, *Spergula arvensis* (Corn spurry), *Arctotheca calendula* (Cape marigold) and *Plantago lanceolata* (Buckhorn plantain). Beef pastoral treatment one, two and three were predominantly *P.*

clandestinum, *E. plana* and ryegrass during winter/spring, however during summer/autumn BPT I, II and BPT III consisted predominantly of *P. clandestinum* and *E. plana*. Beef pastoral treatment four was predominantly *P. clandestinum* and *F. arundinaceae* during summer/autumn.

Beef pastoral treatment one had a significantly higher (P<0.05) percentage *P. clandestinum* than BPT II and BPT IV during winter/spring. Mean seasonal percentage *P. clandestinum* between BPT III and I was not significantly (P>0.05) different. During summer/autumn, BPT II had the lowest (P<0.05) percentage *P. clandestinum*. Beef pastoral treatment one, two and three had a significantly higher (P<0.05) percentage *E. plana* during winter/spring and summer/autumn than that of BPT IV.

Mean seasonal percentage ryegrass and *B. catharticus* for BPT II, and I were significantly higher (P<0.05) during winter/spring than during summer/autumn. The average percentage *F. arundinaceae* in BPT II was less (P<0.05) than that of the percentage *F. arundinaceae* in BPT IV during winter/spring and summer/autumn. Beef pastoral treatment four had the highest (P<0.05) percentage of "other" species during the winter/spring season, whereas mean seasonal percentage "other" species for BPT II was significantly higher (P<0.05) than for BPT II and I.

4.2.3 Comparison of non-destructive methods to determine herbage biomass

The linear relationship between herbage biomass from cut quadrats (destructive method) and that estimated for the non-destructive methods namely the rising plate meter, the comparative yield method and the meter stick for BPT I, BPT II, BPT III and BPT IV, and over seasons are shown in Table 4.8 and Table. 4.9, respectively. Scatter plots of "true/actual" herbage biomass versus herbage biomass estimated by the three methods are presented in Appendix 1 (Figures 10 – 22).

As for the dairy pasture systems, the accuracy of the different methods for estimating herbage biomass was compared using the coefficient of determination values (r^2) between cut quadrats and the herbage biomass estimates for the three different non-destructive herbage biomass estimation methods by assuming best model fit = highest r^2, intercept closest to 0; slope closest to 1 and with the smallest standard error values was defined to be the model that best predicted actual herbage biomass (Draper & Smith 1981). Hand clipping values and herbage biomass estimates were positively correlated ($P<0.05$) for the rising plate meter, comparative yield method and the meter stick (Appendix 2, Table 1).

For the beef pastoral treatment one, the coefficient of determination varies between 0.78 and 0.83 between the non-destructive methods. The comparative yield method and the rising plate meter resulted in nearly similar linear relationship between “true/actual” herbage biomass and estimated biomass.

For beef pastoral treatment two the rising plate meter resulted in the highest r^2 value, the lowest intercept value, SE values closest to 0, and the slope value closest to 1. The rising plate meter resulted in the overall best model fit, for BPT II for predicting herbage biomass.

For beef pastoral treatment three, the coefficient of determination vary between 0.70 and 0.82 for the different non-destructive methods. The meter stick and the rising plate meter resulted in nearly similar linear relationship between “true/actual” herbage biomass and estimated biomass. For beef pastoral treatment three, the meter stick and the rising plate meter resulted in the overall best model fit for predicting herbage biomass.

For beef pastoral treatment four the meter stick resulted in the highest r^2 value, the lowest intercept value, SE values closest to 0 and the slope value closest to 1. The meter stick resulted in the overall best model fit, for BPT IV for predicting herbage biomass.

Table 4.8 Coefficient of determination (r^2), intercept, standard error of the intercept (SE^I), slope and standard error of the slope (SE^S) values between cut quadrats and herbage biomass (kg DM ha^{-1}) estimates for the non-destructive methods for BPT I, BPT II, BPT III and BPT IV. Measurement took place between June 2008 and April 2009. Note: The model with highest r^2, intercept closest to 0; slope closest to 1 and with the smallest standard error values was defined to be the model that best predicted actual herbage biomass (Draper & Smith 1981).

		Non-destructive methods		
BPT		**Rising plate**	**Comparative yield**	**Meter stick**
I	r^2	0.83	0.82	0.78
	r	0.91 *	0.91 *	0.88 *
	Intercept	215.58	357.42	326.35
	SE^I	212.82	204.85	236.14
	Slope	1.00	0.89	0.93
	SE^S	0.11	0.11	0.12
II	r^2	0.76	0.73	0.58
	r	0.87 *	0.85 *	0.76 *
	Intercept	225.98	341.41	453.69
	SE^I	195.22	195.65	247.69
	Slope	0.9	0.82	0.69
	SE^S	0.13	0.13	0.15
III	r^2	0.81	0.70	0.82
	r	0.90 *	0.84 *	0.91 *
	Intercept	31.04	300.13	227.5
	SE^I	169.52	187.69	145.39
	Slope	1.03	0.86	0.89
	SE^S	0.12	0.14	0.11
IV	r^2	0.53	0.66	0.85
	r	0.73 *	0.81 *	0.92 *
	Intercept	389.56	89.74	263.23
	SE^I	275.97	264.56	139.16
	Slope	0.81	1.13	0.92
	SE^S	0.19	0.20	0.09

* Significant at $P<0.05$

In the beef pastoral systems the rising plate meter resulted in higher r^2 values (r^2 = 0.76 – 0.83) than that of the meter stick (r^2 = 0.58 – 0.82) and the comparative yield method (r^2 = 0.70 - 0.82) for three out of four of the beef pastoral treatments (BPT I, BPT II, BPT III). Martin *et al*. (2005) also concluded that the rising plate meter was more effective in estimating herbage biomass than the meter stick and the visual estimation method in beef pastures. However, for beef pastoral treatment four the meter stick resulted in the strongest relationship in this study. Beef pastoral treatment four consisted mainly of a two/three-mixed species stand, while the other beef pastoral treatments (BPT I, BPT II and BPT III) were more heterogeneous stands. Harmoney *et al*. (1997) also looked at methods of estimating herbage biomass in pastures with varying species compositions. They compared the leaf canopy analyser, canopy height measurements, a modified Robel pole and a rising plate meter, with herbage availability determined by clipping. Data were pooled for the whole season and the Robel pole had the most robust linear equation for use in multiple species pastures, with a r^2 value of only 0.63.

As found in the dairy pastoral systems, the accuracy of the non-destructive methods varied considerably betweens seasons. The correlation coefficient values between cut quadrats and herbage biomass estimates for all three non-destructive herbage biomass estimation methods increased from winter/spring to summer/autumn for BPT II, BPT III, BPT IV. For beef pastoral treatment one, the r^2 values between cut quadrats and herbage biomass estimates for the rising plate meter and the comparative yield method decreased from winter/spring to summer/autumn, whereas r^2 value for the meter stick increased as the stands became less heterogeneous. As found in the dairy pastoral systems, the species composition of the different dairy pastoral treatments had a definitely affect on the accuracy of the non-destructive herbage biomass estimation methods. Furthermore, the study demonstrated how difficult it is to find an accurate, consistent method for predicting herbage biomass in mixed-species beef pastoral systems.

Table 4.9 Coefficient of determination (r^2) values between cut quadrats and herbage biomass (kg DM ha^{-1}) estimates for the non-destructive methods, for BPT I, BPT II, BPT III and BPT IV for winter/spring and summer/autumn between June 2008 and April 2009. Note: Best model fit = highest r^2 (Draper & Smith 1981).

		Non-destructive methods		
BPT	**Seasons**	**Rising plate**	**Comparative yield**	**Meter stick**
I	Winter/spring	0.86	0.87	0.70
	Summer/autumn	0.84	0.78	0.84
II	Winter/spring	0.64	0.48	0.31
	Summer/autumn	0.90	0.93	0.85
III	Winter/spring	0.67	0.57	0.76
	Summer/autumn	0.89	0.75	0.85
IV	Winter/spring	0.01	0.00	0.45
	Summer/autumn	0.71	0.95	0.95

4.2.4 Evaluation of the dry-weight rank method for botanical analysis

The “true/actual” botanical composition and that estimated by the dry-weight-rank method (non-destructively) are shown in Tables 4.10 to 4.13. The species composition (*P. clandestinum*, *Eragrostis plana*, ryegrass, *B. catharticus*, *L. corniculatus*) estimates from the dry-weight-rank method and hand clippings were non-significantly (P>0.05) different for BPT I (Table 4.10). All species within BPT I, were estimated within a 5% accuracy of the “true/actual species composition estimated by hand clippings.

Table 4.10 Botanical composition (%) (species) determined by hand clipping (clip) and the dry-weight-rank (DWR) method on BPT I for winter/spring and summer/autumn between June 2008 and April 2009. Differences between means (n = 3) within a line for a species with P<0.05 indicate that differences significantly deviated from zero. LSD (0.05) compares between clip and DWR values for individual species within treatments.

BPT	Species	Season	Clip	DWR	LSD (0.05)
I	*P. clandestinum*	Winter/spring	46^{a}	46^{a}	**6.66**
		Summer/autumn	56^{a}	58^{a}	**6.46**
	E. plana	Winter/spring	27^{a}	25^{a}	**2.93**
		Summer/autumn	33^{a}	29^{a}	**5.57**
	Ryegrass	Winter/spring	13^{a}	14^{a}	**4.29**
		Summer/autumn	2^{a}	2^{a}	**1.55**
	B. catharticus	Winter/spring	5^{a}	6^{a}	**2.89**
		Summer/autumn	1^{a}	1^{a}	**1.26**
	L. corniculatus	Winter/spring	4^{a}	2^{a}	**3.05**
		Summer/autumn	5^{a}	5^{a}	**2.00**

As with the case with BPT I, the species composition (*P. clandestinum*, *Eragrostis plana*, ryegrass, *B.catharticus* and *L. corniculatus*) from the dry-weight-rank method did not differ significantly (P>0.05) from hand clippings for BPT II (Table 4.11). All species within BPT II were estimated within a 5% accuracy of the “true/actual” species composition.

The species composition (*P. clandestinum*, *E. plana*, ryegrass, *D. glomerata*, *F. arundinaceae*, *T. repens)* from the dry-weight-rank method were closely similar (P>0.05) to hand clippings for BPT III (Table 4.12). All species within BPT III were, as with BPT II and I, estimated within 5% accuracy of the “true/actual” species composition.

Table 4.11 Botanical composition (%) (species) determined by hand clipping (clip) and the dry-weight-rank (DWR) method on BPT II for winter/spring and summer/autumn between June 2008 and April 2009. Differences between means (n = 3) within a line for a species with P<0.05 indicate that differences significantly deviated from zero. LSD (0.05) compares between clip and DWR values for individual species within treatments.

BPT	**Species**	**Season**	**Clip**	**DWR**	**LSD (0.05)**
II	*P. clandestinum*	Winter/spring	19[a]	18[a]	**3.83**
		Summer/autumn	33[a]	36[a]	**3.28**
	E. plana	Winter/spring	25[a]	27[a]	**5.14**
		Summer/autumn	32[a]	30[a]	**5.72**
	Ryegrass	Winter/spring	36[a]	32[a]	**8.70**
		Summer/autumn	7[a]	6[a]	**3.94**
	B. catharticus	Winter/spring	8[a]	8[a]	**4.38**
		Summer/autumn	1[a]	3[a]	**3.10**
	L. corniculatus	Winter/spring	6[a]	4[a]	**3.88**
		Summer/autumn	10[a]	9[a]	**2.76**

For beef pastoral treatment four (Table 4.13), the dry-weight-rank method and hand clippings gave nearly similar (P>0.05) estimates of *P. clandestinum* and *E. plana* for winter/spring and summer/autumn. Percentage *F. arundinaceae* estimated between the dry-weight-rank method and hand clippings for winter/spring were also closely similar (P>0.05). However, the dry-weight rank method under-estimated (P<0.05) the percentage *F. arundinaceae* estimated by the destructive method during summer/autumn with 4%.

Table 4.12 Botanical composition (%) (species) determined by hand clipping (clip) and the dry-weight-rank (DWR) method on BPT III for winter/spring and summer/autumn between June 2008 and April 2009. Differences between means (n = 3) within a line for a species with P<0.05 indicate that differences significantly deviated from zero. LSD (0.05) compares between clip and DWR for individual species within treatments.

BPT	**Species**	**Season**	**Clip**	**DWR**	**LSD (0.05)**
III	*P. clandestinum*	Winter/spring	35^{a}	32^{a}	**12.26**
		Summer/autumn	53^{a}	54^{a}	**8.94**
	E. plana	Winter/spring	19^{a}	19^{a}	**5.17**
		Summer/autumn	27^{a}	24^{a}	**5.76**
	Ryegrass	Winter/spring	18^{a}	19^{a}	**14.05**
		Summer/autumn	2^{a}	1^{a}	**1.57**
	D. glomerata	Winter/spring	13^{a}	19^{a}	**10.49**
		Summer/autumn	10^{a}	12^{a}	**6.56**
	F. arundinaceae	Winter/spring	2^{a}	2^{a}	**3.12**
		Summer/autumn	2^{a}	1^{a}	**1.61**
	T. repens	Winter/spring	2^{a}	1^{a}	**1.73**
		Summer/autumn	0^{a}	1^{a}	**0.68**

Table 4.13 Botanical composition (%) (species) determined by hand clipping (clip) and the dry-weight-rank (DWR) method on BPT IV for winter/spring and summer/autumn between June 2008 and April 2009. Means (n = 3) within a line for a species with different superscript letters indicate significant (P<0.05) differences. LSD (0.05) compares between clip and DWR for individual species (within treatments (BPT I, BPT II, BPT III).

BPT	**Species**	**Season**	**Clip**	**DWR**	**LSD (0.05)**
IV	*P. clandestinum*	Winter/spring	28^{a}	29^{a}	**5.50**
		Summer/autumn	57^{a}	59^{a}	**8.32**
	E. plana	Winter/spring	4^{a}	3^{a}	**5.17**
		Summer/autumn	4^{a}	5^{a}	**5.76**
	F. arundinaceae	Winter/spring	27^{a}	37^{a}	**12.25**
		Summer/autumn	27^{a}	23^{b}	**4.10**

The results of the beef pastoral systems indicate, as with the dairy pastoral systems, that the dry-weight-rank method of botanical analysis is an accurate means of estimating botanical composition of cultivated beef pastoral systems. The contribution of 96% of all species within the beef pastoral systems was estimated within 5% accuracy of the “true/actual” value of species determined by hand clipping.

CHAPTER 5

GENERAL CONCLUSIONS AND RECOMMENDATIONS

Accurate prediction of herbage biomass and/or botanical composition is essential for extending appropriate grazing management practices and enabling pasture and feed allocation and feed budgeting to be under taken on farms. These predictions ensure sustainable pasture and feed allocation, as well as feed budgeting on farm-level. In this study the possibility of predicting herbage biomass and/or botanical composition of both dairy and beef pastoral systems from using simple and cost-effective non-destructive methods, instead of more accurate, time-consuming quadrat cutting method, were investigated.

5.1 NON-DESTRUCTIVE HERBAGE BIOMASS ESTIMATION

The results indicated that within limits the non-destructive methods used in this study, is a reliable way of monitoring herbage biomass of cultivated pastures. All three non-destructive methods (rising plate meter, comparative yield method and the meter stick) provided accurate measurements. As this study only dealt with the accuracy of each of the non-destructive methods it is recommended that future researchers study the repeatability, precision, lack of user bias, efficiency, or a combination of some or all of the above.

The rising plate meter was the only instrument purchased from a manufacturer. The meter stick was easily and cheaply constructed from readily available materials. However, all methods were relative inexpensive to use. From experience it was clear that the rising plate meter and the meter stick were the easiest to use. However, the comparative yield method was also simple and less tedious than clipping. The learning curve of the comparative yield method was steeper than that of the rising plate meter and the meter stick because of the standards that had to be set. Furthermore, plant heights were not easily defined and therefore measurements were more subject to bias and error. A way to compensate for these problems, the same observer had to be used each time if possible, which is supported by many other researchers.

The linear equations obtained, allows rapid herbage biomass determinations that could be made with all three non-destructive methods. The rising plate meter was the most accurate for estimating herbage biomass in three out of four beef pastoral systems. On the other hand, the meter stick was the most accurate in all treatments within the dairy pastoral system. This had to be seen to the background that the mean seasonal botanical composition between and within the dairy pastoral systems as well as for the beef pastoral systems were found to be different from each other. While the beef pastoral systems were overall more heterogeneous (*Pennisetum clandestinum*, *Eragrostis plana*, *Lolium multiflorum*, *Lolium perenne*, *Bromus catharticus*, *Lotus corniculatus*, *Dactylis glomerata*, *Festuca arunidnaceae*), the dairy pastoral systems consisted mainly of two-species in the mixed pastures namely *P. clandestinum* and ryegrass. These differences in species composition may explain the different results in terms of biomass prediction between the beef pastoral systems and the dairy pastoral systems. Therefore, the accuracy of these non-destructive methods to predict herbage biomass is dependent on not only the specific pastoral system, but also the plant species present. This finding suggest that with more information of the sward characteristics, a check list of features may be developed to assist with the selection of the most appropriate method of herbage biomass estimation. Furthermore, results from this study were obtained from separate calibration sets. It is therefore recommended that all instruments used for non-destructively estimating herbage biomass should be calibrated separately for each occasion.

Although most researchers are of the opinion that the cutting of vegetation is the best way to estimate pasture productivity for both beef and dairy pastoral systems, in practice on a farm, it is very unlikely that farmers will cut plants in quadrats to determine herbage biomass. This method is not only time consuming, but does not provide the timely results needed for day-to-day management decisions. In contrast, the non-destructive methods evaluated in this study, took little more time to collect measurements than is necessary to walk through a paddock.

The accuracy required for any observation is dependent on the objective of estimation. Based on the results of this study, all tested methods are suitable on farm-level and also for pasture research studies on a larger scale. However, in grazing studies that are conducted on relatively small areas and with a relatively small number of grazing animals, these methods may not give such accurate herbage biomass estimates. When accurate herbage biomass estimates are required, cutting is still recommended. Thus, when a researcher is confronted with a large-scale experiment from which an assessment of pasture yield has to be made, with limited time and labour, it is recommended that sufficient accurate results can be obtained from a more heterogeneous pasture with the rising plate meter. The same is applicable for a two-mixed pasture by measuring production through the meter stick method.

When grazing animals are involved, these methods could be used to determine initial stocking rates and indicate periods in which animals should be added or removed from pastures in a grazing system, the so-called put-and-take system. These methods would also serve as a useful tool for pasture managers in grazing animal production systems to set stocking rates at levels necessary to balance forage supply and demand in pastures that may have uneven species distribution and plant densities. However, all measurements used in allocating herbage biomass, need to be tempered by careful observations of plants and grazing animals. This is necessary to make sure that animals are adequately fed and swards are not under- or overgrazed to ensure sustainable animal production.

Cattle farmers with a mixed species sward should also bear in mind that the amount of dry herbage biomass measured is usually no all utilizable. The main problem with determining feed available for livestock is that all herbage biomass estimation methods measure the amount of dry herbage biomass present at a given time, without accounting for consumption by grazing animals. Herbage biomass is defined as “total aboveground biomass of herbaceous plants regardless of grazing preference of availability” and forage is “herbage which is available and may provide food for grazing animals or be harvested for feed”. Forage is most directly related to the amount of herbage biomass measured in (near) monospecific swards. However, in mixed swards the value of forage depends largely on two factors namely the botanical composition (ratio palatable versus non-palatable species) and the amount of dead material accumulated through under grazing and trampling. Information on sward characteristics or the classification of the fractioning of the clipped sample into different utilization categories can assist with this problem. Therefore, when taking measurements, it must always be remembered to take these above-mentioned factors into consideration to avoid false predictions.

5.2 NON-DESTRUCTIVE BOTANICAL COMPOSITION ESTIMATION

The study indicated that the dry-weight-rank method of analysis is an efficient and accurate means of determining the botanical composition of cultivated dairy and beef pastoral systems. The dry-weight-rank method is easy to use and can be combined with recording the frequency of less common species. It has the advantage that being dry-weight based, the estimates are directly related to herbage quantity, where cover-based estimates are not. The dry-weight method gave acceptable estimates of species composition on the cultivated pastures, used in this study, even though the multipliers, originally proposed by ‘t Mannetjie & Haydock (1963) were derived from a quite different ecosystem.

It should be noted that the dry-weight-rank method only gives relative percentage estimates of species composition. If actual species weights are required, total herbage biomass must be measured and multiplied by the percentage estimates for each species. Total herbage biomass would be much easier to measure than standing biomass per species. Botanical composition from the dry-weight-rank method can also be linked to herbage biomass on a plot basis by an independend method (‘t Mannetjie 2000). A well-tested method is available, namely BOTANAL (Tothill *et al*. 1992) that combines the dry-weight-rank method with another visual estimate, namely the comparative yield method (Haydock & Shaw 1975) (Chaper 2, section 2.2.2.2). Unfortunately, these linkages were not done in this study and need future investigation. Furthermore, this study only dealt with the accuracy of the dry-weight-rank method and it is recommended that future researchers study the efficiency of the method. For this purpose it would be necessary to determine the time it takes to conduct a dry-weight-rank survey versus a destructive sampling survey.

The dry-weight-rank method can be a valuable tool in both research and farm management activities. Analysis of herbage species composition, especially determination of the herbage biomass of each species present at the time of analysis, has the potential to evaluate animal production from cultivated pastures. Grazing capacity, animal performances and responses to supplementary feeding may be strongly influenced by the species composition of the herbage on offer. Therefore, for sustainable animal production it is essential to determine the botanical composition of pasture.

The dry-weight-rank method can also be used to establish preferences indices for different species in grazed pastures. By determining species composition through mass in fixed quadrats before and after a short period of intensive grazing, a comparison can be made of the amount of each species of the herbage eaten and that on offer at the start of grazing.

CHAPTER 6

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APPENDIX 1

FIGURES
NON-DESTRUCTIVE HERBAGE BIOMASS ESTIMATION METHODS

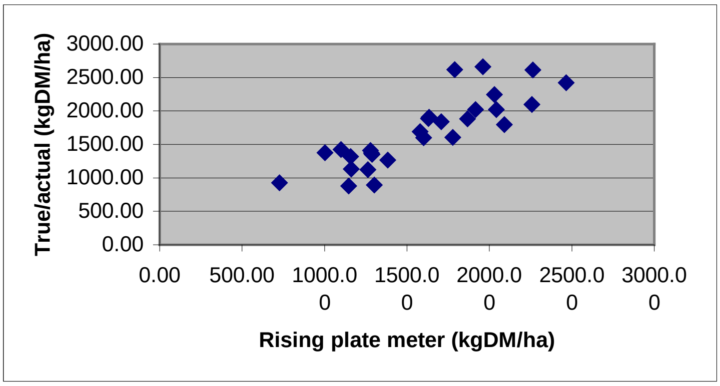

Figure 1: Relationship between the herbage biomass estimated with the rising plate meter and the true/actual herbage biomass for DPT I.

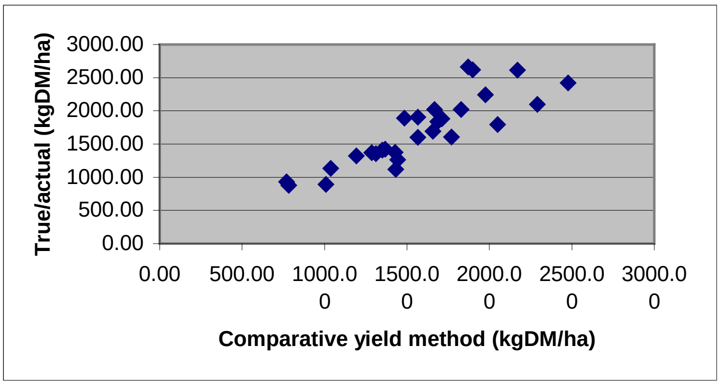

Figure 2: Relationship between the herbage biomass estimated with the comparative yield method and the true/actual herbage biomass for DPT II.

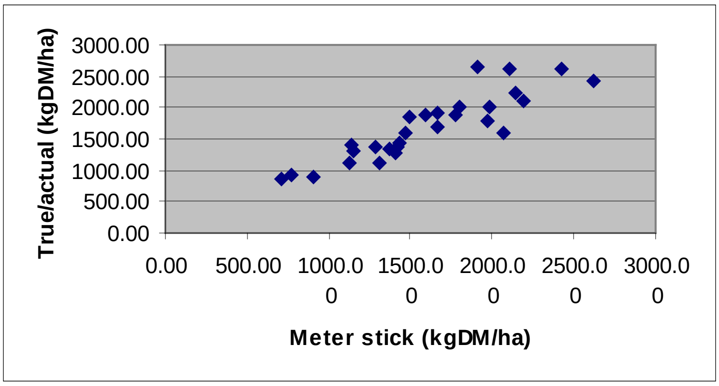

Figure 3: Relationship between the herbage biomass estimated with the meter stick and the true/actual herbage biomass for DPT III.

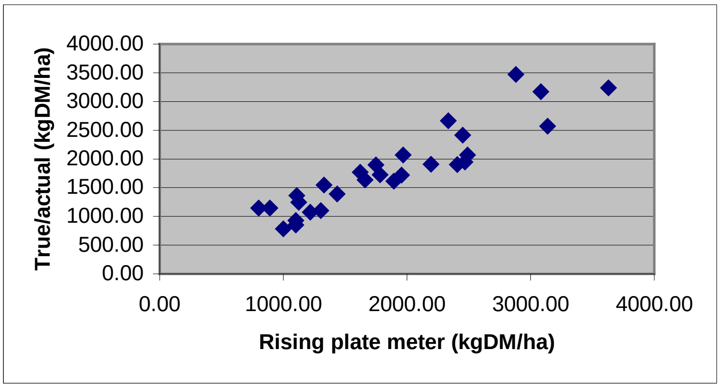

Figure 4: Relationship between the herbage biomass estimated with the rising plate meter and the true/actual herbage biomass for DPT II.

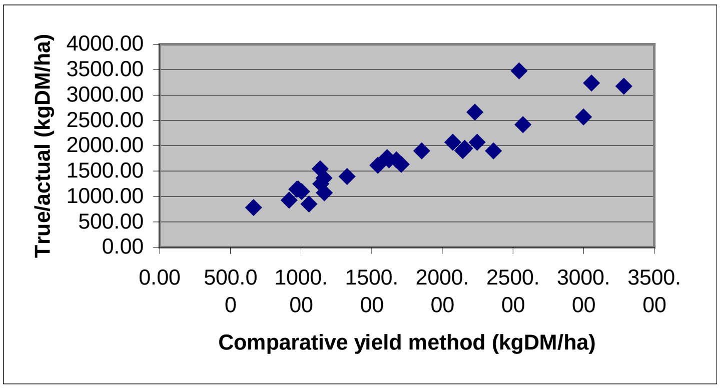

Figure 5: Relationship between the herbage biomass estimated with the comparative yield method and the true/actual herbage biomass for DPT II.

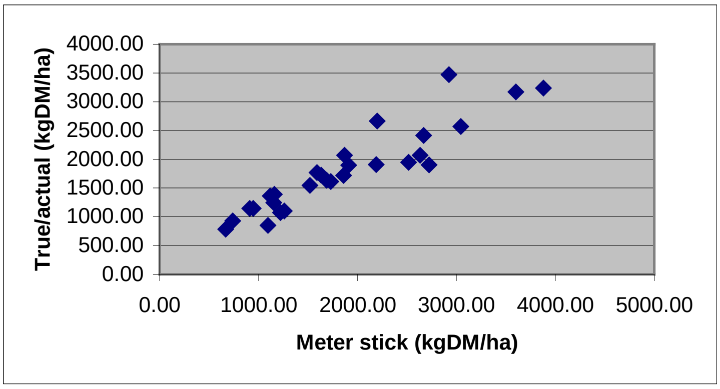

Figure 6: Relationship between the herbage biomass estimated with the meter stick and the true/actual herbage biomass for DPT II.

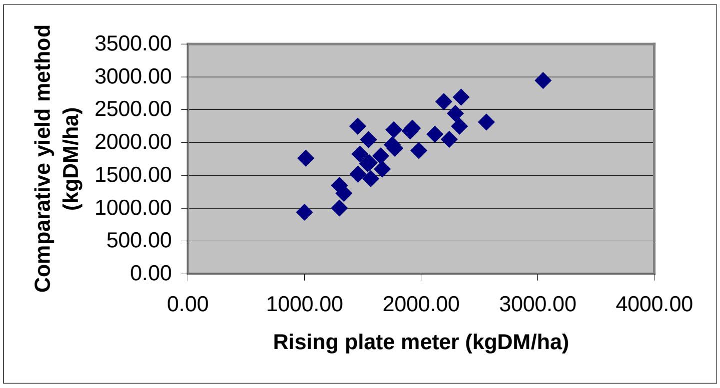

Figure 7: Relationship between the herbage biomass estimated with the rising plate meter and the true/actual herbage biomass for DPT III.

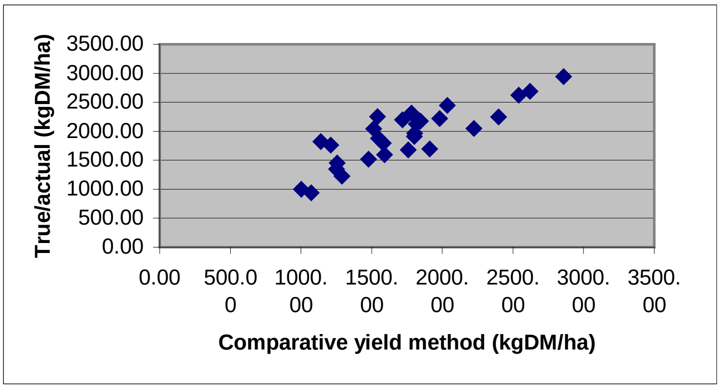

Figure 8: Relationship between the herbage biomass estimated with the comparative yield method and the true/actual herbage biomass for DPT III.

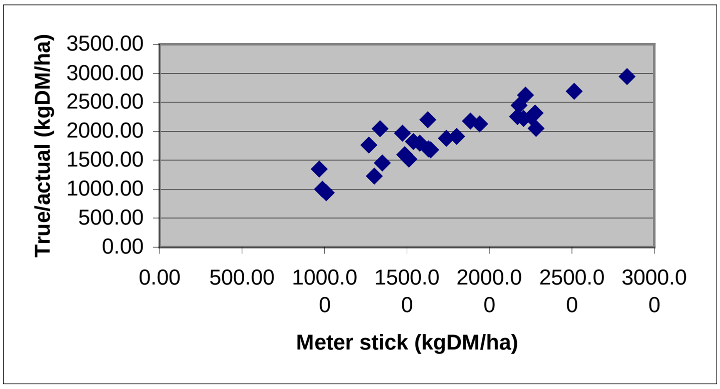

Figure 9: Relationship between the herbage biomass estimated with the meter stick and the true/actual herbage biomass for DPT III.

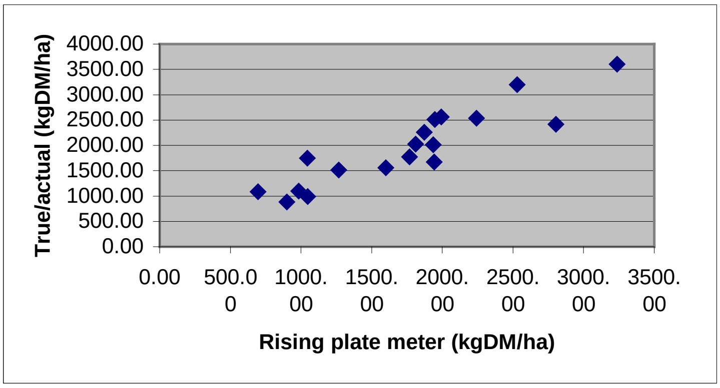

Figure 10: Relationship between the herbage biomass estimated with the rising plate meter and the true/actual herbage biomass for BPT I.

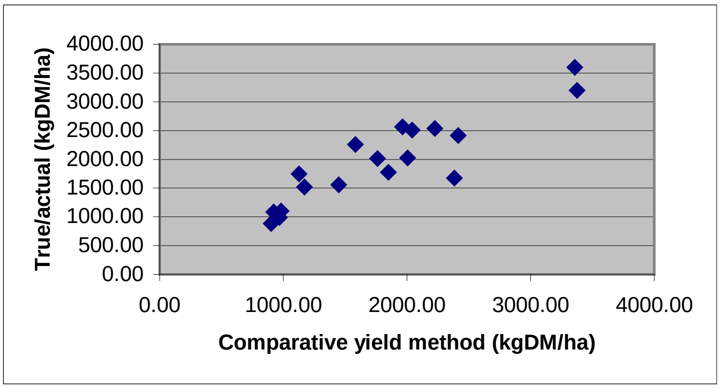

Figure 11: Relationship between the herbage biomass estimated with the comparative yield method and the true/actual herbage biomass for BPT I.

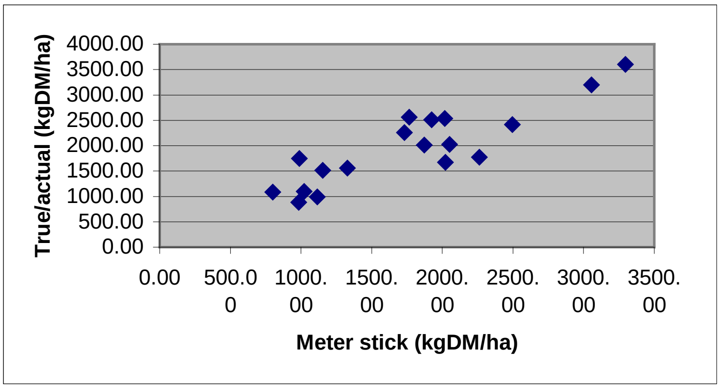

Figure 12: Relationship between the herbage biomass estimated with the meter stick and the true/actual herbage biomass for BPT I.

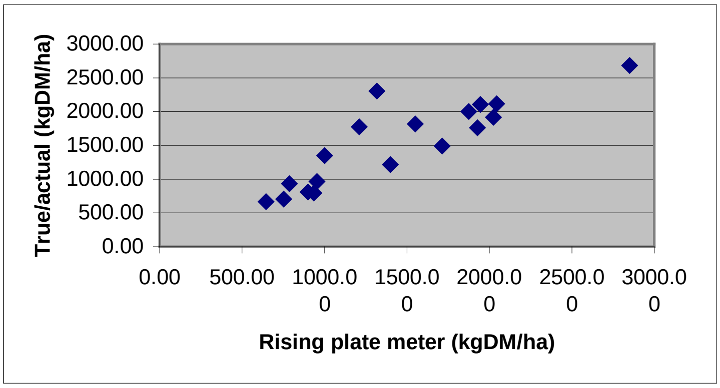

Figure 13: Relationship between the herbage biomass estimated with the rising plate meter and the true/actual herbage biomass for BPT II.

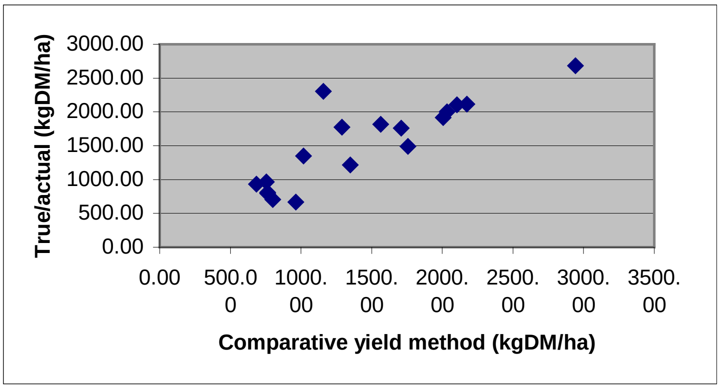

Figure 14: Relationship between the herbage biomass estimated with the comparative yield method and the true/actual herbage biomass for BPT II.

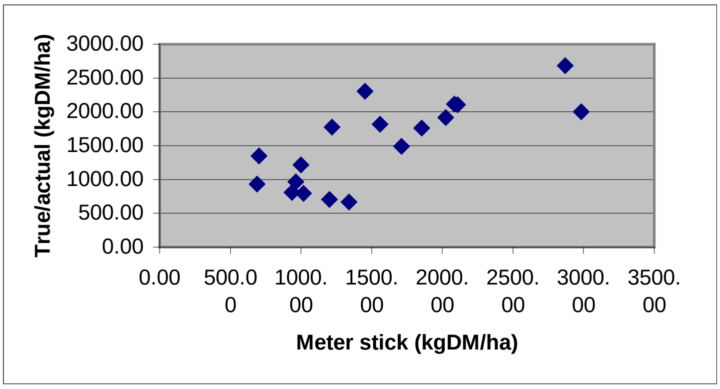

Figure 15: Relationship between the herbage biomass estimated with the meter stick and the true/actual herbage biomass for BPT II.

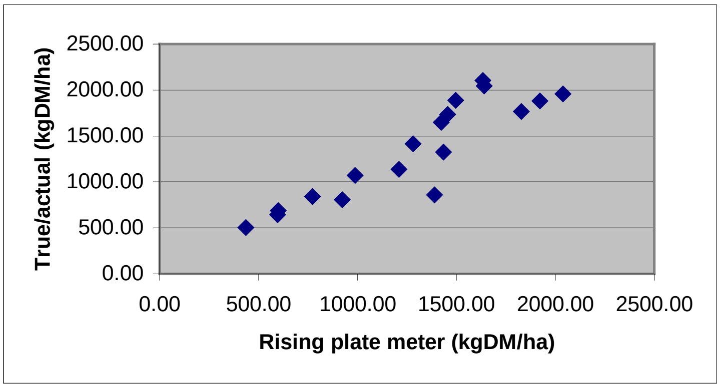

Figure 16: Relationship between the herbage biomass estimated with the rising plate meter and the true/actual herbage biomass for BPT III.

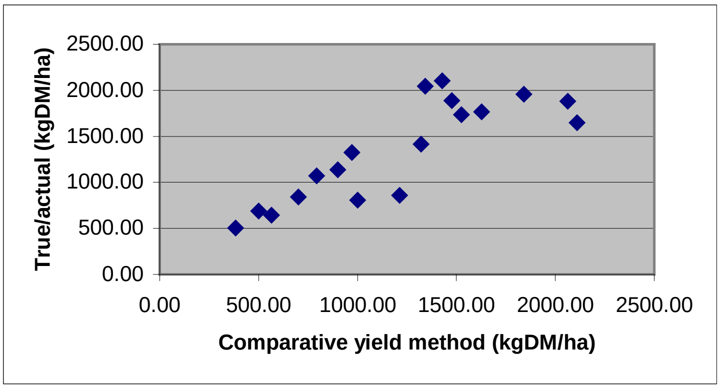

Figure 17: Relationship between the herbage biomass estimated with the comparative yield method and the true/actual herbage biomass for BPT III.

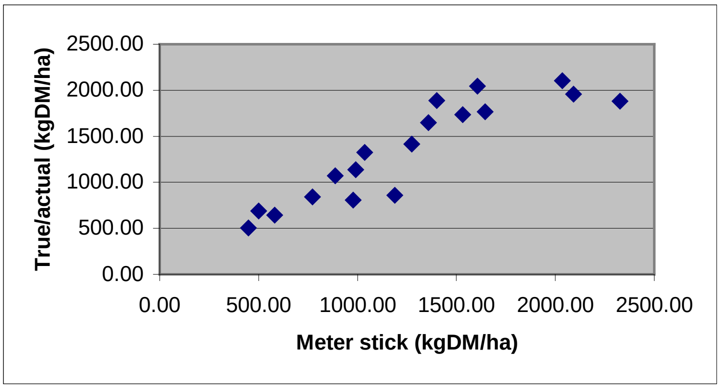

Figure 18: Relationship between the herbage biomass estimated with the meter stick and the true/actual herbage biomass for BPT III.

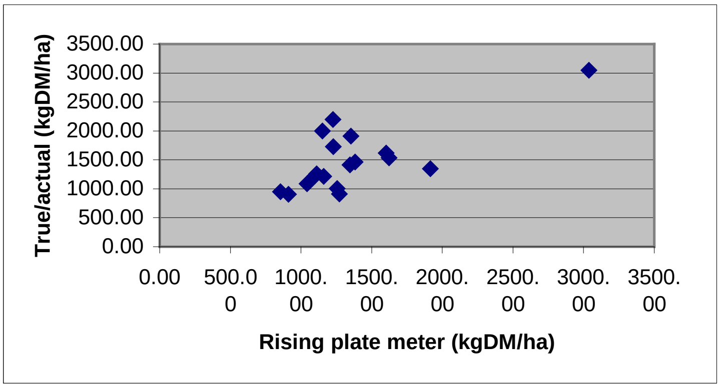

Figure 19: Relationship between the herbage biomass estimated with the rising plate meter and the true/actual herbage biomass for BPT IV.

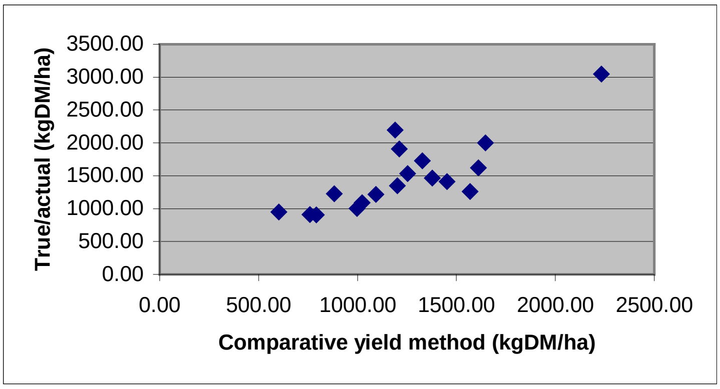

Figure 20: Relationship between the herbage biomass estimated with the comparative yield method and the true/actual herbage biomass for BPT IV.

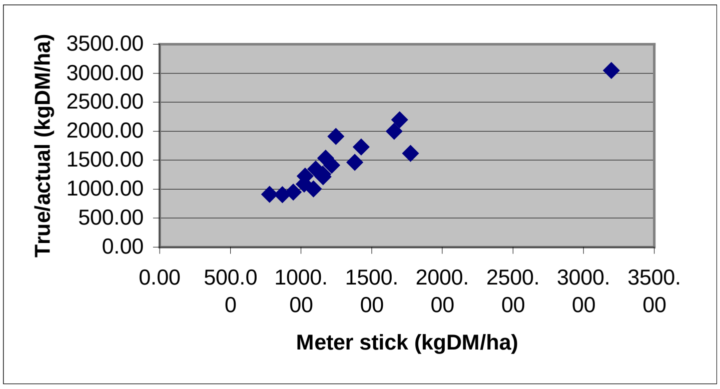

Figure 21: Relationship between the herbage biomass estimated with the meter stick and the true/actual herbage biomass for BPT IV.

APPENDIX 2

TABLES (P-Values)

NON-DESTRUCTIVE HERBAGE BIOMASS ESTIMATION METHODS

Table 1: P-value for the non-destructive methods for the dairy pastoral systems (DPT I, DPT II, DPT III) and beef pastoral treatments (BPT I, BPT II, BPT III, BPT IV) between June 2008 and April 2009. Note: P<0.05 indicates significance.

	Non-destructive methods		
Treatment	**Rising plate**	**Comparative yield**	**Meter stick**
DPT I	0.0000	0.0000	0.0000
DPT II	0.0000	0.0000	0.0000
DPT III	0.0000	0.0000	0.0000
BPT I	0.0000	0.0000	0.0000
BPT II	0.0000	0.0000	0.0002
BPT III	0.0000	0.0000	0.0000
BPT IV	0.0006	0.0000	0.0000

Table 2: P-value for the non-destructive methods for the dairy pastoral systems (DPT I, DPT II, DPT III) and beef pastoral treatments (BPT I, BPT II, BPT III, BPT IV) for winter/spring and summer/autumn. Note: P<0.05 indicates significance.

		Non-destructive methods		
Treatment	**Season**	**Rising plate**	**Comparative yield**	**Meter stick**
DPT I	Winter/spring	0.00001	0.00000	0.00000
	Summer/autumn	0.00144	0.00510	0.00300
DPT II	Winter/spring	0.00001	0.00000	0.00000
	Summer/autumn	0.00321	0.00580	0.00560
DPT III	Winter/spring	0.00000	0.00000	0.00000
	Summer/autumn	0.00834	0.00210	0.00090
BPT I	Winter/spring	0.00090	0.00070	0.00920
	Summer/autumn	0.00010	0.00070	0.00020
BPT II	Winter/spring	0.01768	0.05710	0.15530
	Summer/autumn	0.00003	0.00000	0.00010
BPT III	Winter/spring	0.01338	0.03020	0.00480
	Summer/autumn	0.00004	0.00130	0.00010
BPT IV	Winter/spring	0.79475	0.91820	0.06860
	Summer/autumn	0.00208	0.00000	0.00000