

TECHNIQUES FOR MEASURING PASTURES

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**PASTORAL AND VETERINARY INSTITUTE
HAMILTON**

Agriculture Victoria

AUSTRALIA

February 1996

*First published in 1991 as:
Department of Agriculture Technical Report series No. 191*

Second edition (revised and enlarged) 1996

NATIONAL LIBRARY OF AUSTRALIA
CATALOGUING-IN-PUBLICATION DATA

Cayley, J.W.D. (John William Douglas), 1938- .
Techniques for measuring pastures.

Bibliography.
ISBN 0 7306 64295

1. Pastures. I. Bird, P.R. (Patrick Rodney),
1942- . II. Victoria. Dept of Agriculture, Energy and Minerals.
III. Title.

633.2020287

The second edition has been revised and expanded and includes the following extra sections:

- Accuracy, precision and bias
- Sampling
- Weighting
- Data entry
- Measurement of forage shrubs
- Identification of individual plants

Printer: Spec Speedi Print
59 Gray Street, Hamilton
Victoria

PREFACE TO SECOND EDITION

Pasture measurements are integral to grassland experimentation. Such measurements are equally essential whether assessing the herbage present in a pasture, examining changes in growth or pasture quality during the growing season, studying the influence, on the sward, of a range of superimposed treatments, or investigating the effects of pathogens on plant production.

This second edition of 'Techniques for Measuring Pastures' by John Cayley and Rod Bird provides a critical analysis of the range of techniques available for making such pasture measurements, including their appropriateness for specific requirements. A very good chapter on General Principles is followed by a consideration of a range of topics, including the optimal layout of field plots, the sampling of such plots, the number of observations required to achieve an acceptable Standard Error and laboratory procedures.

The publication clearly shows the authors' considerable knowledge of, and wealth of experience in, pasture measurements. It contains much sound practical advice for those involved in grassland R & D. In addition, the Further Reading, including seminal works on the subject, and the comprehensive list of references, do much to put the work into an international context. It is a must for those newly entering the field of pasture research in Australasia, and a most valuable reference for experienced pasture workers.

Alec Lazenby

Coordinator, Australian Grass and Perennial Legume Improvement Programs (AGIP) and (APLIP).

PREFACE TO FIRST EDITION

This publication by John Cayley and Rod Bird is an excellent handbook for pasture scientists. It is a particularly useful resource for younger workers with less experience of pasture measurements, but will also be an informative *aide-mémoire* for senior scientists.

The strength of 'Techniques for Measuring Pastures' is that it incorporates a vast range of experience in using pasture measurement techniques over many years. In addition it draws on a range of published material from throughout the world.

In the current and foreseeable economic climate when, regrettably, there is a tendency worldwide to spend less on training of scientists and support staff, this publication will be of tremendous value.

Pasture research, development and extension here in Victoria have over the past couple of years received a major boost from 'Pastures for Profit', a part of the Government's Economic Strategy for Agriculture. This has resulted in the recruitment of a number of young scientists and support staff, who may well be the first customers of this handbook.

I am sure that you will find it to be an invaluable resource for pasture workers, both young and old.

T.G. Reeves

Project Manager – 'Pastures for Profit'

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ACKNOWLEDGMENTS

We are grateful to Les Jones, Stuart Crosbie and John Reynolds (biometricians past or present with Agriculture Victoria) for making helpful suggestions on various drafts of this paper, and to Tony McGowan (formerly from Ellinbank Dairy Research Institute) and David Hume (AgResearch, New Zealand) for suggestions that we have incorporated in this edition. Mardi Bawden drew the scene on the cover. We also acknowledge financial support provided by Victoria's PASTURES FOR PROFIT Agricultural Strategy Project for printing the first edition of this handbook.

1. GENERAL PRINCIPLES

1.1 ACCURACY, PRECISION AND BIAS

Measuring pastures generally involves the use of sampling to estimate the magnitude of the variables of interest. We have introduced the terms accuracy, precision and bias at the beginning in order to reduce some of the confusion that may exist about these terms.

The accuracy of a measurement is the closeness of this measurement to its true value. For example, the accuracy of using a ruler to measure length would be improved if we allowed for a systematic error in the ruler, or took care to eliminate parallax errors.

Precision in a technical sense is distinguished from accuracy in that it refers to the reliability of estimating a value by repeated measurements. The estimate of the mean derived from samples has its own standard error, and the lower the standard error of the estimate, the higher the precision. As a rule, the precision of an estimate will be higher if more samples are taken than if each sample is measured more accurately.

If the mean from a set of samples differs in a systematic fashion from the mean of the pasture as a whole, the sample is said to be biased.

Concepts of precision and bias should always be borne in mind when sampling.

1.2 SAMPLING

If the size of plots is small, it may be possible to measure the whole plot, but usually some form of sampling is needed in order to estimate the population mean for the attribute of interest (McIntyre 1978; Tothill 1978; Shaw *et al.* 1976; Sandland *et al.* 1976). For small plots, samples should be taken at random; the points to sample being pre-determined using sets of random numbers to define the x-y coordinates for each point.

1.2.1. Shape and size of sampling units

The sampling unit is usually square, rectangular or circular. For our purposes, a frame used to delineate a sample of pasture, irrespective of its shape, will be called a quadrat. In general, a rectangular quadrat or plot with its long axis directed down the gradient in production results in the least variability between sampling units. If quadrats are to be used to sample a crop sown in rows, it is necessary to have one side of the quadrat equal to a multiple of the distance between rows, and to align the quadrat so that this side is perpendicular to the rows. This ensures that the same number of rows are present in the quadrat wherever it is placed. Accuracy would be reduced if the size of the quadrat allowed either three or four rows to be included depending on how it was placed on the ground. Better still, use a quadrat whose length is equal to the sowing width of the drill (*i.e.* the distance between outside tynes + the distance between adjacent tynes). This allows for the variation in seeding rate or fertilizer rate between rows, and for the effect of wheel tracks which often have a big positive or negative effect on establishment. Measurements at the Pastoral and Veterinary Institute, Hamilton (PVI) have shown that variation over the length of a common brand of seed drill can be considerable. For a

given setting and 50 revolutions of the drive-wheel, mean output of fertilizer over the 18 'rows' across the width of the implement was 187 g. The sample standard deviation was 43.5 g and the range varied from 138 g to 291 g per 'row'!

For a given area sampled, the estimate of the mean is more precise if a large number of small units is measured, rather than a smaller number of larger units (McIntyre 1978). McIntyre (1978) also pointed out that for quadrats or units smaller than the size of the individual plants, the variance of the mean rises with increasing quadrat size until the size of the quadrat equals that of the plants. Thereafter the variance falls. He concluded that the size of the sampling unit should be at least several times the size of the dominant plant species.

1.2.2 Edge effects and errors due to placement

Another factor that should be considered when counting plants or measuring herbage within small areas is the error of accurately delineating the boundary of the area to be assessed (edge effects). This error is greater in small quadrats because the length of edge per unit area of quadrat increases as the size of quadrat decreases. Hutchinson (1967) used a cutting device to take cores of pasture from closely grazed swards. This reduced edge errors considerably. For a given quadrat area, edge effects are minimised if the quadrat is a circle or square. A second type of edge effect is due to herbage being pushed in or out of the quadrat when it is placed in position. This error is also less marked as the size of the quadrat increases. The problem is overcome to some extent by using a metal frame consisting of three sides of a square, which can be placed and manoeuvred into position on the ground with much less disturbance to the vegetation than a four-sided frame or ring. The three-sided frame should be used for quadrats smaller than 0.1 m² in area. Errors due to placement are less if pastures are very short.

1.2.3 How can you allow for variation between operators?

It is inevitable with some methods, particularly visual assessments, that there will be considerable variation among operators. If there is any chance that this could happen it is imperative that each operator assesses a complete block of treatments. That will minimise within-block variance and maximise the chance of detecting differences among treatments. In some cases, for example where differences among blocks are to be tested, it is essential that each operator assess every plot in the experiment. In such cases the required total sampling effort (e.g. 30 observations per plot) would be shared among the operators. Thus, three operators would each make 10 observations across the full range of the plot. It is often possible to assess bias or difference between operators if 'operator' is used as a term or factor in the statistical analysis.

1.2.4. Stratified random sampling

Stratified random sampling should be used in large grazing experiments. Each plot is divided into a number of strata, and samples are taken at random from each stratum. This ensures that intensity of sampling is the same over the whole area of the paddock, and is necessary to ensure that the mean of a set of observations is not biased. An excellent description of this procedure is given by Mitchell and Glenday (1958).

1.2.5. Concomitant measures

Concomitant measures, or double sampling (McIntyre 1978), is the term given to the process of calibrating a set of indirect or non-destructive measures by measuring the

actual value of the variable of interest on a sub-set. The chief advantage of this practice is the saving in time (see 2.1, 2.4.4, 2.5.1, 2.5.2, 2.5.3 and 4.2).

1.2.6. Ranked sets

The ranked set method of McIntyre (1952) gives an unbiased estimate of the mean and variance and also considerably reduces the number of sample areas required to be measured. The approach is much more efficient than selecting at random the same number of quadrats to measure. The method may be illustrated by taking five sets of five random samples within the plot, ranking the samples visually or by meter (see 2.5.2 and 2.5.3) within each set, then measuring the highest ranked sample in set one, the second highest in set two through to the fifth highest in set five. (In practice the ranks selected for cutting would be randomised among the sets). Ranking is too difficult when more than five quadrats are used per set and, in any case, there is little extra precision to be gained. The sampling is improved if the plot is sub-divided into several equal sized strata (with no well-defined gradients within each portion) and clusters of ranked sets are distributed within each stratum: *e.g.* take four plot sectors and in each locate three sets of three quadrats, then in each sector cut the highest from one set, middle rank from another and the lowest from the remaining set.

Spatial variation within a plot, for example localised changes in soil fertility associated with stock camps or sites previously occupied by trees, may mean that subsequent sets of samples taken at random may not be able to assess changes in time with precision, as some areas may not always be represented. Often, a precise assessment of change is of greater interest than precise estimates of the measurement on a given occasion.

As a general principle, if changes in time are to be assessed precision is improved if the same areas or plants are measured on successive occasions; this applies particularly to measurements that are not likely to result in changes that may influence subsequent measurements. The method of measuring net pasture growth described in section 3.1.1 relies on this concept.

We feel sure that more attention should be given to planning how to sample pastures. The principle applies to other tasks such as soil sampling, which if undertaken on the same fixed transects or strata should be better able to detect the changes in time associated with changes in fertilizer use. It is essential to plan the method of sampling to suit the objectives of the study.

1.3 WEIGHTING

In some cases the value of a sample may have to be weighted if its value is to be included in computing the sample mean.

Let us assume, for example, that the area of a paddock occupied by a sheep camp is 2%, and that pasture growth on the camp area is greater than elsewhere in the paddock because of increased soil fertility. If 10 pasture cages are to be used to measure growth, and one of these cages is located in the sheep camp, the mean of the set of 10 samples will be biased upwards if the growth from the cage on the sheep camp is included. It is possible to ignore the sheep camp, but that will bias the estimate of mean pasture growth for the plot downwards.

The mean growth for the plot averaged over 10 cages without weighting is:

$$\frac{(\mathbf{Cage}_1 + \mathbf{Cage}_2 + \dots \mathbf{Cage}_{10})}{10} \text{ that is } \frac{\sum_{i=1}^{10} \mathbf{any cage}_i}{10} \text{ or } 0.1 \times \sum_{i=1}^{10} \mathbf{any cage}_i$$

The cage on the camp represents $\frac{1}{50} = 0.02$ of the area. The remaining cages must

therefore represent $\frac{49}{50}$ of the area, or $\frac{49}{50 \times 9} = 0.1089$ each.

Accordingly, the mean growth for the plot is given by:

$$0.02 \times \mathbf{camp cage} + 0.1089 \times \sum_{i=1}^9 \mathbf{other cages}_i$$

Similar situations will be found elsewhere due to local influences of shelter-belts, isolated trees, saline areas, watering-points and so on. Further examples of weighting values are given at 3.1.5 and Table 14.

1.4 DATA ENTRY

Ideally the number of times that data have to be written down, typed or copied must be kept to a minimum in order to avoid transcription errors. Transcription errors can be kept to minimum as it is now possible to interface most electronic balances and load-cell readers to a portable computer, though there may be difficulties of using expensive office equipment in dusty field conditions or in the rain!

If data have to be recorded by hand, the data should be entered in specially prepared data sheets which are kept in a secure binder, or in a book. Avoid loose bits of paper for data entry; they are surprisingly easy to miss-place!

With randomized block or lattice designs, data should be collected from one block or row at a time. This guards against the problems that arise should interruptions occur due to break-downs or other unexpected causes.

It is essential that the data entry sheets have the plots in the order or pattern that are set out in the field, preferably with the alignment of the plots to north and some clear land-mark marked clearly. It is also a good idea to have a template sheet that is the same size as the recording sheet with all the treatments, blocks, rows and columns clearly marked.

Data should be typed into or electronically captured by a personal computer. If typing, it is essential to check the data against the recording sheets. This is facilitated if the spread-sheet on the computer is designed in the same way as the data sheet. Avoid the situation where columns in the data sheet must be copied into rows on the spread sheet. Make it a rule not to save a file unless the data have been checked, preferably twice. This saves a lot of time in the long run. Data should be 'backed-up' to safeguard against accidental loss.

2. MEASUREMENT OF PASTURE MASS

Information on the amount of pasture present is required to:

- determine the mass of pasture present (**PM**), usually as dry matter (**DM**)
- determine pasture growth or its utilisation by animals
- determine the effect of species, fertiliser, management and other factors on productivity of pasture.

2.1 METHODS (GENERAL)

Two types of methods are used. These have been termed destructive and non-destructive ('t Mannetje 1978).

Destructive methods involve the harvesting of the herbage from all experimental units (plots or quadrats), whilst non-destructive methods involve the measurement of a variable (*e.g.* electrical capacitance, height, an estimate of yield, the settled height of a weighted disk, length or point quadrat hits) that can be related to quantity by harvesting the pasture in a small number of sampling units (see 1.2.5).

Destructive methods are appropriate for measurements of hay crops and for assessing the differences between pasture species or cultivars under conditions of mowing and grazing. Fertiliser requirements are also often assessed by mowing areas that are usually ungrazed for the duration of the investigation (usually one growing season) but care needs to be taken to ensure that the results can be applied to grazed pasture, if this is intended, as ungrazed trials may not take account of the recycling of nutrients (see Brockman *et al.* 1970); also the magnitude of the response to fertilizer between grazed and ungrazed trials may differ (Cayley and Hannah 1995), making it hazardous to calculate optimum fertilizer rates using data from ungrazed trials alone.

Non-destructive methods are appropriate if it is necessary to measure the same plant or plants at a later date, or to save labour. McIntyre (1978) has provided a means of quantifying the cost-benefit of using a non-destructive method.

2.2 ACHIEVING THE PRECISION REQUIRED

2.2.1 How many sample units are required to obtain an estimate of the mean with a satisfactory degree of precision?

This will depend on the variability of the pasture, usually expressed as the coefficient of variation (**CV**). The **CV** is the sample standard deviation (*s*) expressed as a percentage of the mean (Table 1). The results are based on about 300 observations of the settled height (**h**) of a weighted disk. Pasture mass was related to **h** using a regression equation (see 2.5.2). For the purposes of this exercise the *s* of **PM** has been calculated directly from the *s* of **h**, assuming that the regression was without error, *i.e.* that only random variation in the population is considered.

Table 1. Variation in pasture mass (*PM*) of pasture set-stocked with sheep during late winter to early summer.

MONTH	<i>PM</i> (kg/ha)	<i>s</i>	<i>CV</i> %	observations
August	530	140	27	325
October	1440	400	28	300
December	2840	1550	55	300

The *CV* varies with the amount of pasture present. Under conditions of abundant pasture the sheep are able to graze selectively, leading to a marked increase in the variability of pasture mass.

Snedecor (1962 p. 501) shows how the number of measurements required ($P < 0.05$) to obtain an estimate of the mean with a given allowable error (*L*) can be calculated if *s* is known:

$$\text{if } L = \frac{1.96s}{\sqrt{n}}, \text{ where } n = \text{the number of units,}$$

i.e. $L \approx 2 \times \text{SE of mean}$,

$$\text{then } n \approx \frac{4s^2}{L^2} \text{ or } n \approx \frac{4CV\%^2}{L\%^2}$$

An example from a sheep grazing experiment at the PVI is shown in Table 2. The results are based on 30 observations of the settled height of a weighted disk. The *s* estimates are similar to those in Table 1.

In this case also, the *s* of *PM* has been calculated directly from the *s* of *h*, assuming that the regression was without error.

Table 2. Numbers of observations required to estimate mean pasture mass (*PM*) at a range of allowable errors (*L*) at two stocking rates (SR) of sheep.

Plot and date			<i>PM</i> (t/ha)	<i>s</i> (t/ha)	<i>CV</i> (%)	Observations required if <i>L</i> (t/ha)=			
						0.01	0.10	0.20	0.50
(A)	Low SR	11/8	2.10	1.10	52	48000	480	120	20
	(10/ha)	10/11	4.40	2.40	55	233000	2330	580	90
(B)	High SR	11/8	0.60	0.13	21	720	7	2	1
	(18/ha)	10/11	1.20	0.27	23	2920	30	7	1

Note

- (i) As stocking rate is increased, pastures become more uniform.

- (ii) It is absurd to report **PM** with more precision than the nearest 100 kg/ha. Many authors persist in presenting **PM** to the nearest kg! (Even with 300 observations we probably should not have presented means to the nearest 10 kg in Table 1). When **PM** is very low, however, reporting means to the nearest two significant figures is satisfactory. It is often convenient to report **PM** in t/ha with one or two decimal places rather than in kg/ha (see Table 2).
- (iii) As **PM** increases so does variability (**CV**). Obviously, with greater **PM** more observations are needed.
- (iv) As **L** increases (*i.e.* the degree of accuracy required decreases), the sampling effort required drops away steeply. Before-and-after grazing measurements of **PM** are often used to determine intake. This is fraught with error - *e.g.* for cattle eating 10 kg/d, **L** must be ≤ 100 kg/ha in order to even roughly estimate true intake.

2.2.2 How many observations are needed per plot to detect significant differences in pasture mass between two plots?

The formula is based on a ‘one-tailed’ test (Snedecor 1962, p. 250) for observed differences, and introduces the concept of the least significant difference (**LSD**) between two means:

$$LSD = t \sqrt{\frac{2EMS}{n}} \quad \text{i.e.} \quad n = \frac{t^2 \times 2EMS}{LSD^2}$$

where **n** = number of observations in each mean

EMS = error mean square (*i.e.* residual variance)

t = Student’s ‘t’ value for the appropriate error degrees of freedom (**df**).

Cochran and Cox (1957, p. 20) present this as follows for expected differences:

$$R \geq 2\left(\frac{S}{D}\right)^2 (t_1 + t_2)^2$$

where:

R = computed number of replicates

S = residual standard deviation (rsd), *i.e.* \sqrt{EMS}

D = true difference that you want to detect

t₁ = ‘t’ test value - need to guess R, hence get **df** and ‘t’ table value for, say,
P = 0.95 level

t₂ = **2(1 - P)** value of ‘t’

P = proportion of experiments in which differences are to be detected
(*e.g.* 0.95).

Consider a situation where you wish to detect true differences (***D***) of 100, 200 or 500 kg/ha between two plots, using the weighted falling disk method, and consider a possible range of precision of 100 - 2000 kg/ha (Table 3).

Table 3. Number of observations required per plot to detect a difference (***D***) in ***PM*** between two plots.

Standard deviation (<i>s</i>)	<i>D</i> (kg/ha)		
	100	200	500
100	28	9	3
300	240	60	10
500	650	160	30
1000	2600	650	100
2000	10400	2600	400

Note

- (i) When the range of ***PM*** is great, or botanical composition variable, the *s* may be high - this will occur in spring and more observations are then needed.
- (ii) When you need to detect small differences between plots (*e.g.* 100 kg DM/ha) you need a proportionally greater sampling effort. Often that is not possible. Don't delude yourself - decide at the outset whether the objective can be achieved.

2.2.3 How many replicates of a treatment and how many samples per plot are required to detect differences among treatments?

This problem may be approached using data supplied by Jerry Chin of the PVI. Four cultivars of fodder brassicas were established at Hamilton in two randomised blocks. Each of the eight plots were sampled (*n* = 33 - 53) to determine mean plant weight (g). The mean values $\pm s$ were:

Kestrel	0.42 \pm 0.55 (<i>n</i> = 92)
Rangi	0.65 \pm 0.94 (<i>n</i> = 92)
Aran	1.11 \pm 1.25 (<i>n</i> = 86)
Pasja	1.37 \pm 1.64 (<i>n</i> = 85)
overall mean	0.87 \pm 1.21 (<i>n</i> = 355)

We wish to determine whether any differences were significant and/or if we should have had more replication, or more sampling effort.

The analysis of variance (Table 4) gave no significance (variance ratio < 2). You can also see that the variation within plots was enormous:

$$CV \text{ i.e. } \frac{100\sqrt{1.252}}{0.87}, \text{ exceeds } 100\%.$$

Table 4. ANOVA table for brassica fodder crops

Source of variation	<i>df</i>	<i>ss</i>	<i>ms</i>	Variance ratio
Between plots				
BLOCK	1	2.265	2.265	
PLOT (VARIETY)	3	49.39	16.46	1.66
BLOCK . PLOT (error)	3	30.23	10.08	
Within plots				
BLOCK . PLOT . PLANT	347	434.6	1.252	
Total	354	516.5	1.459	

Mean number of plants measured per plot = $\frac{355}{8} = 44.375$

The variance between plots (V_b) = $\frac{19.08 - 1.252}{44.375} \approx 0.199$ CV=45%

The variance within plots (V_w) = 1.252 CV=128%

With **R** replications and **n** samples per plot for differences between two means:

Variance of the difference (**VD**) = $\frac{2(V_b + \frac{V_w}{n})}{R}$

Standard error of the difference (**SED**) = \sqrt{VD}

The least significant difference (**LSD**) = **SED** × **t'** for the appropriate error degrees of freedom

For the brassicas, where **R** = 2, **n** = 44 and **LSD** = 1.518 g/plant, we can compute the effect of altering replications and number of samples per plot. **SED** values have been calculated for a range of **R** and **n** and the **LSDs** (5% level) for each estimate are presented in Table 5.

Table 5. How many replicates of each treatment and samples per plot are needed to detect differences between cultivars?

Estimated **LSD** (g/plant) at 5% level^a

Error <i>df</i>	Number of replicates (R)	t'	Number of observations/plot (n)				
			10	25	50	100	1000
3	2	3.182	1.81	1.59	1.51	1.46	1.42
6	3	2.447	1.14	1.00	0.95	0.92	0.89
9	4	2.262	0.91	0.80	0.76	0.73	0.72
15	6	2.131	0.70	0.61	0.58	0.57	0.55

^a A difference between means is significant if it exceeds the estimated **LSD**.

It is immediately clear that a modest increase in replication (**R**) would allow one difference (Pasja v. Kestrel) to be detected (**LSD** = 0.95 g). It is also clear that this could be accomplished spending less overall effort sampling, *i.e.* have four replicates with 10 samples/plot rather than two replicates and 50 samples/plot. Increasing the sampling effort alone (*e.g.* from 10 to 1000 plants/plot) accomplishes little and is very costly.

Variation of the extent shown above is commonly encountered - but not realised - and greater replication is required to overcome the problem.

Decide what treatment difference you wish to show as being significant (**LSD**) then, from the above formula, determine the required **R** and **n**. To do this you need a reasonable estimate of **V_w** and **V_b**. If the whole plot is harvested:

$$V_w=0 \text{ and } V_b=EMS \text{ so } VD = \frac{2V_b}{R} \text{ and } SED = \sqrt{VD} \text{ or } \sqrt{\frac{2EMS}{R}}$$

If there are several replicates and several treatments of an existing field experiment, and a new measurement is to be attempted, an estimate of **V_w** and **V_b** can be obtained by doing a limited sampling (**n** = 2 or more) on every plot and analysing the results before proceeding further. To allow this you must not pool the plot samples (*e.g.* soil cores) because that would preclude the estimation of **V_w**.

2.3 LABORATORY PROCEDURES

Similar laboratory procedures initially apply to most samples of pasture brought in from the field.

2.3.1 Drying and weighing

The cut herbage should be placed in plastic bags together with a cardboard label for identification. Use pencil or a black ball-point pen for writing on labels as blue ink will wash out if the herbage is wet. The label should be put into the bag after the sample so that it can be read through the plastic. Preferably, the bag should be 'rolled', not tied (see 2.4.2).

A balance with a tare facility is essential if the samples are to be used to determine the dry matter content of herbage harvested from mown strips. The balance should be 'tared' with a new plastic bag and label, as this allows the fresh weight of the samples to be measured without opening the bags. (A considerable amount of moisture condenses on the plastic and this weight must be taken into account). If only DM yield is required and the sample is contaminated with soil, the herbage should be washed by agitating it by hand in a sink full of clean cold water. The herbage is scooped out with a sieve or mesh-bottomed drying tray.

After weighing, the fresh sample plus cardboard tag is placed in a tray or string bag for drying (preferably in a forced-draught oven) to constant weight at 100°C. Use a temperature of 60°C if it is intended to carry out a chemical analysis. The dried herbage

must be weighed hot, as it will regain moisture after cooling. The best method of weighing is to use an electronic balance with a tare facility as follows:

- (i) Remove the cardboard tag and place tray full of grass on balance and press the tare key - display will read '0.0'.
- (ii) Empty tray, brush out remaining herbage and replace tray on balance - display will read negative (*e.g.* '-13.4 g').
- (iii) The dryweight, 13.4 g is written on the tag.

This procedure is quicker and less prone to error than transferring the herbage to a standard tared container or platform for weighing.

Do not use paper bags for drying herbage, as circulation of air through the herbage and the oven will be inadequate. Overloading non forced-draught ovens is a dangerous practice as 'hot spots' can develop which can lead to a fire. This happened at the PVI in 1985 after an oven without provision for ventilation was crammed with paper bags full of grass! If a forced-draught oven is not available, small samples must be used, and sub-sampling must be done (see 2.3.2).

If herbage harvested with a rotary mower is contaminated with dirt, washing should be avoided, as soluble material is readily lost from macerated herbage. The proportion of foreign matter (dirt, *etc.*) must be determined after drying by taking a sub-sample (see 2.3.2) and sorting by hand. Where mud has adhered to the leaves, a correction based on an ash determination may be warranted.

Computation of results (usually total yield and yield of sown species) is best done using a programmable calculator or personal computer, preferably with a printout. This eliminates arithmetic errors and allows checking with the oven and field books.

2.3.2 Sub-sampling

The objective of sub-sampling is to produce a sample of a manageable size that still retains the characteristics of the original sample. A procedure known as quartering makes it possible to select very small representative sub-samples from a large sample (>100 g dry matter) of pasture.

The material to be sub-sampled is first spread in an even heap on a bench. Where herbage is very long, at this stage it is best to reduce the size using hand shears; unless the material is to be subsequently sorted for botanical composition. In that case cutting of material will separate flower heads from the plants and make the job difficult or impossible. The heap is then mixed and divided into quarters and opposite quarters are collected together. The two heaps thus produced are inspected, and if similar in appearance, one heap is discarded and the remaining heap, if larger than the required size of sub-sample, is mixed and the quartering procedure continued. If the heaps differ in appearance it will usually be due to the presence of a large piece of clover or grass stem in one of the heaps, and it will be necessary to snip the large bits of herbage into a number of small pieces, mix the heaps together and continue quartering until a suitably sized sub-sample is selected.

If very small sub-samples are taken, it may pay to take a duplicate sub-sample from the heap of discarded material. This adds confidence to the estimate and is still quicker than sorting a large sample.

2.3.3 Hand separation

A sub-sample of fresh pasture small enough to be sorted in a few minutes (1-10 g DM) is selected by the quartering procedure, and sorted into the desired classes. Duplicate sub-samples should be taken for sorting to improve precision. Herbage selected for hand separation should be stored under refrigeration or it may be oven-dried or freeze-dried and stored in the dark (to prevent fading) until processed. The components are weighed on a dry basis to 0.001 g and the percentage computed. A third sub-sample is required if the duplicates do not agree within 10% units.

2.4 LAYING OUT AND MEASURING AN UNGRAZED EXPERIMENT

2.4.1 Layout

The plots should be rectangular with the long axis aligned along the gradient in production (usually in the direction of the slope). The width of the plots should be at least twice that of the mower if this method of assessment is to be used. To determine yield a strip is cut down the middle of each plot. This reduces the influence of neighbouring plots and eliminates edge effects. For large plots, more than one strip per plot will increase accuracy, but some uncut pasture should be left between each strip. A headland should be provided at each end of the plots. This, and similar corridors between replicates, should be wide enough to manoeuvre mowers etc. with ease. It is convenient to mark the corners of each plot with wooden pegs.

The experiment should be securely fenced to exclude animals, and there should be a border of at least 2 m between the headlands and the fence.

2.4.2 Measurements using a mower

- Decide on a cutting height and stick to it for the experiment. If conditions are very wet, rotary mowers will not work properly. The wheels sink in, and herbage is mashed into a pulp that sticks to the underside of the mower.
- Before mowing the plots you should mow headlands and corridors between the replicates at the cutting height intended for mowing the plots, and remove this herbage from the site.
- The best containers for herbage samples are plastic bags. These should all be the same weight in order to simplify weighing in the laboratory (see 2.3.1).
- After the strip is cut, the usual procedure is to weigh the herbage with a spring balance or load cell and then take a sample consisting of several small grabs for drying. If the yield is very small, weighing in the field is too inaccurate, and all the herbage should be put in the bag for weighing later. The sample is identified with a cardboard label with the plot number, and perhaps the experiment number or name. Write the fresh weight of herbage harvested from the strip on the label

using a waterproof felt-tip marker, black ball-point pen or pencil. It saves time and reduces errors if the labels are arranged in the correct order on the day before the plots are to be cut with all details except fresh weight filled in. The label should be put in the bag after the sample, so that it can be read through the plastic. In order to prevent loss of moisture, the bags should be sealed with a slip knot or clothes peg. Avoid overhand knots or rubber bands, which are fiddly and difficult to untie. If no more than $\frac{1}{3}$ full, the bags can be 'rolled'. This saves time and is worth learning. To do this:

- Put the fingers (not thumbs) of both hands into the bag (knuckles up) and pull it open.
 - Maintaining this tension, pinch the side of the bag closest you between thumb and index finger about 2 cm from the top, and rotate both hands away from you (palms up).
 - Push the edge held with the thumbs down over the bottom corners of the bag.
 - Tuck bottom corners of bag in with your fingers.
- Cutting at a height above ground level may mean the results are biased (some species may produce significantly more herbage below mower height than others). If the total yield is required, additional sampling of the stubble will be necessary. One method would be to use an electronic capacitance meter or visual assessment to estimate the amount of stubble remaining. Some quadrats will have to be cut in order to calibrate the data. Differences in *PM* below cutting height will be mainly a consequence of differences in species composition. These differences will affect calibration, which may therefore be required for each plot. A better approach is to use an unbiased selective method (McIntyre 1952) to choose a few quadrats in each plot for hand cutting to ground level (see 2.4.3). The appropriate unit to cut is probably a core of about 10 cm diameter (Hutchinson 1967). It is simpler to leave the sampling of stubbles until all the plots are harvested.
 - If the mower is being used for the first time, the width of cut should be determined by measuring the width of the cut strips. About 20 measurements should be sufficient to obtain a good estimate of the mean. This procedure is more accurate than measuring the mower.
 - For comparisons of different species or cultivars, it is essential to measure the contribution of the sown species to the total yield. If a sickle-bar mower is used, a sub-sample can be taken for hand-sorting (see 2.3.2 and 2.3.3). If a rotary mower is used, the herbage will be shredded and separate samples for sorting must be taken. The best way to do this is to use shears to harvest a number of equal areas (say 25 cm^2) from the uncut herbage adjacent to the mown strips, in a similar manner to 'toe-cuts' (see 5.4). The herbage for each strip is pooled.
 - After harvesting is completed, all the herbage remaining on the experimental site should be mown. If this is not done, the uncut herbage on the side of the strips may affect the growth of plants on the strip by shading them, or by competing for water and/or nutrients. The excess herbage may be removed or preferably, spread evenly over the plot to simulate the return of nutrients that occurs in a grazed

pasture (Lynch 1966). This is especially important in experiments that are to last for more than one year. This procedure is facilitated by the use of special mulching mowers which pulverize the herbage and blast it down into the cut sward. This increases the rate of break-down and hence release of nutrients into the soil.

- All samples should be weighed and dried as soon as possible in order to reduce respiratory losses (see 2.3.1). Samples for hand sorting should be stored under refrigeration but not frozen.
- The samples taken for hand sorting should be sub-sampled with a quartering procedure (see 2.3.2) and sorted fresh into the fractions required (usually sown species and remainder). The various components are then dried and weighed.
- The frequency of mowing affects yield. If mowing is used to estimate the likely production of grazed pasture, a cutting frequency of 4 weeks will under-estimate production. A yield closer to that of grazed pasture will be obtained with a cutting frequency of 12 weeks (Cayley and Hannah 1995). However, better information on seasonal growth will be obtained with more frequent mowing.
- A mowing frequency of longer than 4 weeks should not be used for long-term experiments, as the returned clippings may smother the mown pasture.

2.4.3 Quadrat cutting

Sample areas from 0.1 to 1 m² may be located at random within the test area and all herbage harvested to ground level. Take care to minimise errors due to placement (see 1.2.2). Sharp dagging shears are suitable for harvesting pasture from areas of 0.1 m² or less. When harvesting sample areas much larger than 0.1 m² a shearing handpiece may be appropriate; the most convenient type is an electric handpiece powered by a vehicle's battery. Lawn trimmers powered by a re-chargeable battery are unsuitable. We prefer hand-operated shears because of their low cost, simplicity and utility.

To obtain the desired precision rather more of the plot may be 'destroyed' than is acceptable and an alternative method may be preferable. However, the non-destructive methods (see 2.5.1, 2.5.2 and 2.5.3) are not always satisfactory, particularly where there is a large variation in species composition or maturity within or between treatment plots or periods of measurement.

The method of ranked sets (see 1.2.6) considerably reduces the number of sample areas required to be cut. We have also employed an approach differing only in that the median rank of each set of five quadrats is cut (or retained for measuring growth over the following period). We found that the median closely approximated the mean, at least for **PM**.

2.4.4 Pasture meters and visual methods

The methods outlined in Section 2.5 are appropriate for plots of the size used for mowing strips (see 2.4.1) and may be the only practicable way to estimate pasture growth (see 3.1.1) when large numbers of plots are involved or ground conditions do not permit the use of mowers.

When screening lines of pasture cultivars there may be hundreds of small plots to routinely assess and pasture meters or visual assessment may also be the only practical solution to that problem.

- Pasture meters

The use of weighted disks (see 2.5.2 and 3.1.1) or capacitance probes (see 2.5.3) are the method of choice when the plot exceeds 0.5 m² and contains many plants. These methods allow routine assessments to be made on plots without undue disturbance and largely avoid operator bias. If a ranking only of cultivars is intended you may not need to calibrate the instrument to ascertain **PM** in terms of dry matter. This will be true when the calibration is linear and when there are no marked differences among cultivars in the calibration equation (see Crosbie *et al.* 1987). If comparisons on the growth of plants between seasons is required, calibration is needed to enable all data to be expressed on a common basis.

- Visual method

A visual ranking method has been used by Stephen Clark at the PVI to discriminate among selection lines of pasture legumes. The 5-point scoring method is akin to that described in Sections 2.5.1 and 5.7. A score of 1 is given to the plot which appears to have the lowest yield and 5 to the plot which has the greatest pasture mass. All other plots are then rated according to this range. Mean values for a given cultivar or treatment are simply the mean of the replicate scores, assuming that there is a linear relationship between score and plant mass. There is no need to calibrate score with pasture mass. Plant selection is based on mean score.

Some training and experience is needed to avoid substantial bias when attempting to rank pastures on a dry-weight basis (see 2.5.1 and 5.5). This is particularly important when different species or cultivars have dissimilar leaf size or growth habit. While an effort to reduce bias is necessary it should be recognised that it is most unlikely to be completely successful and for this reason visual scoring should only be used to separate treatments or cultivars which differ substantially, *e.g.* identifying the top 10% of cultivars for further selection. The observer must also be aware of the possibility of subjective bias towards or against certain readily recognised cultivars in the experiment. Subjective assessment is often used when screening plants in experiments where only one or a few individuals represent the cultivar. Care must be taken to minimise bias and there must be an adequate range of size (mass) in the plants to perform a realistic scoring appraisal.

2.5 MEASUREMENT OF CONTINUOUSLY GRAZED PASTURES

The large number of samples required to estimate the mean of the population usually necessitates an indirect method of assessment rather than a direct method where herbage is cut from within quadrats.

2.5.1 Method of Haydock and Shaw (1975)

Estimates of the **PM** in a number of quadrats in the area to be assessed are related to a set of quadrats that cover the range of herbage mass in the paddock. A further set of quadrats is cut after all estimations have been completed in order to provide a means of calibrating each individual observer. If more than one area is to be assessed and several observers are available, each observer should assess every area in order to eliminate bias (see 1.2.3).

- Selection of reference quadrats
A set of five reference quadrats serve as a means of assessing estimates made in the field. First, a low yielding area is selected and marked by placing a quadrat on the pasture (Standard 1). Similarly a high yielding area is selected (Standard 5). These areas are chosen so that only rarely would the **PM** within quadrats chosen at random lie outside these limits. Extreme areas, for example a patch of bare ground or the densest pasture in a sheep camp, are not chosen for the limits of the reference quadrats. A position for Standard 3 is then chosen. This is estimated to have a **PM** half way between those of standards 1 and 5. Standards 2 and 4 are then selected. These are estimated to have pasture masses half way between those of 1 and 3, and 3 and 5 respectively. A nine-point scale can be established by selecting standards 1.5, 2.5, 3.5 and 4.5 following the same procedure. For the high-yielding standards, where most of the plant material is close to the ground, it is important to gauge **PM** by handling the pastures as well as by visual appraisal. Some points to note are:
 - (a) Each observer independently selects a position for the prospective mid-point standards. The choice of a mid-point to use as a standard is made after consultation between observers.
 - (b) It is convenient to have standards centrally situated and reasonably close to one another in order to make it easier for observers to inspect the standards from time to time.
 - (c) If the pasture is grazed when observations are made, the standards should be protected by placing pasture cages over them.
 - (d) After establishing the scale, a training period is required during which all observers simultaneously rate a series of quadrats until an acceptable degree of agreement is reached (say within 0.25 of a scale unit). During this period, frequent returns to the standards are necessary.
- Rating of pasture mass
Each observer rates the required number of quadrats in the paddock by placing the quadrat on the pasture in a random fashion; say after every 10 paces. During sampling it is wise to return to the set of standards from time to time to refresh the

memory. The standards should also be inspected after a break (*e.g.* for lunch) or first thing in the morning if sampling takes more than one day.

- **Calibration**
After the rating of quadrats in the paddock is completed, a few sites are chosen by each observer to cover the range from low to high **PM**. A total of 12 sites is suggested. Each observer then independently ranks each of the 12 sites. The herbage in these quadrats is harvested and a calibration is established for each observer by regression of **PM** on score. Always plot the data to detect spurious values and/or to determine whether a curvilinear model might be tested. Adopt this practise for all calibration situations.
- **Processing of samples**
The cut herbage should be placed in plastic bags together with a cardboard label indicating the quadrat number, and dried (see 2.3.1). A separate regression of **PM** on score is computed for each operator, preferably with a printout to permit checking. The rankings made by each individual are then converted to **PM** using that person's own equation, and the mean **PM** for the paddock calculated.
- **Equipment required:**
 - Quadrats 12 square or circular quadrats (area 0.1 m²) numbered 1 to 12.
 - Shears One set of dagging shears for each operator, or shearing handpiece (see 2.4.3) if preferred.
 - Labels Set of five or nine labels with spike for fixing near standards. The labels should be marked 1, 2, 3, 4, 5 or 1, 1.5, 2, 2.5,.....5.
 - Note books Each observer should record their estimates in a note book, as separate calibration equations are used for each person.

2.5.2 Method of weighted disk

We use a 3 kg weighted disk (area 0.10 m²) to relate settled height above ground to **PM** beneath the disk (Figure 1). The disk is gently lowered onto the pasture after the central rod is located on the ground surface. The height is recorded after 5 - 10 seconds settling time. The ease of use of the meter is improved by mounting a small mirror at the top of the tube to enable the scale to be read from above. In this case the scale must be a mirror-image of that shown in Figure 1.

Figure 1. Weighted disk pasture meter and example of calibration.

The number of observations required per plot to give an estimate of the mean meter reading with a given allowable error ($L\%$) may be known from previous work (see 2.2.1). If not, after completing some sampling across the paddock (30 - 100 readings) check the standard deviation of the meter readings to establish the intensity of sampling required to meet your $L\%$ (e.g. 10 or 20%). The disk is calibrated by measuring the **PM** and settled height at a number of sites.

The selection of calibration cuts depend on the likely variability between treatments:

- (i) If the **PM** of only one or two paddocks is required, or if the regression of **PM** on meter reading is likely to vary between treatments due to large differences in botanical composition, use the approach of Crosbie *et al.* (1987) to estimate the slope and curvature of the regression for individual plots or plots having the same treatment. The mean meter reading and its standard deviation (h and s) for each plot or group is used and, depending on the precision required, three, four or six calibration cuts are needed per plot or treatment at the following meter readings:

Three cuts: $h - s\sqrt{\frac{3}{2}}$, h , and $h + s\sqrt{\frac{3}{2}}$

Four cuts: $h - s\sqrt{2}$, h , h , and $h + s\sqrt{2}$

Six cuts: two cuts at each of $h - s\sqrt{\frac{3}{2}}$, h , and $h + s\sqrt{\frac{3}{2}}$

You can take only two cuts per plot ($h-s$ and $h+s$) if you are confident that the regression is linear. If cuts are made in all plots this approach may be adequate.

- (ii) If the relationship between meter height and **PM** over the whole experiment can be represented by a single regression, the paddock or experiment should be sampled at the required sampling intensity. At least 10 meter readings with associated calibration cuts should be made over the entire range of meter heights encountered. Extreme readings should be avoided as these would rarely be encountered in practice, and may result in errors in estimating the true slope and intercept of the regression line. A large range in height can also give a misleading impression of the variance accounted for by the regression (r^2).

At each site, after the meter is read, a metal ring is placed over the disk and the meter removed. Pasture from within the ring is then harvested to ground level with hand shears and dried (see 2.3.1) to get the **PM** for that site. The regression of **PM** on meter reading is then computed (Figure 1).

In our experience it is biologically appropriate to use a curvilinear model to represent the relation between **PM** and settled height of the meter. The best fit is usually:

$$PM = a + b \times height + c \times \sqrt{height}$$

An important advantage of this model is that it gives more realistic values at low **PM**. For this reason there is a strong case for using the curvilinear model whether the coefficient ' c ' is significant or not. Note: when a curvilinear model is used it is necessary to compute the mean **PM** from individual readings of height, not from the mean height. A curvilinear model must therefore not be used on meters (mechanical or electronic) that accumulate meter readings, unless there is a means of retrieving the individual readings for each paddock.

Separate regressions are generally needed for each seasonal assessment of **PM**. Even with inexperienced operators calibration data can be combined to give a single equation, *e.g.* when 17 operators each cut one quadrat selected at random, the range of **PM** was 2-5 t DM/ha, r^2 0.89, *rsd* 0.32 t DM/ha and **CV** 8% (Figure 1). With three experienced operators each cutting six measured quadrats, a typical result was **PM** range 0.2-5.2 t/ha, r^2 0.96, *rsd* 0.28 t DM/ha and **CV** 16%. The *rsd* always provides the best ‘test’ of the regression; *e.g.* when the range of **PM** is low the r^2 value may also be low but the *rsd* may be acceptable.

We prefer this ‘falling-plate’ disk (see Bransby *et al.* 1977) to the ‘automatic’ rising-plate disk (see Earle and McGowan 1979) where height is recorded cumulatively each time the meter is placed on the pasture and the central rod pushed down onto the ground. The results with the latter disk are heavily dependent on the operator's style, and calibration may not be consistent with the meter's usage over the paddock. Individual measurements obtained with the ‘falling plate’ also enable an on-site frequency distribution to be plotted (see 2.5.4) and within-plot variability (V_w) to be estimated (see 2.2.3). The ‘falling plate’ disk is also more suitable for measuring herbage growth (see 3.1.1), as it is difficult to replace the meter in exactly the same spot if an ‘automatic’ rising plate meter is used; furthermore, with the ‘automatic’ meter you will be locked into using a linear calibration model (see above).

2.5.3 Electronic capacitance meters

We have used and tested a number of these instruments, including the early 16 prong models, twin prong and modern single-prong units (*e.g.* Vickery *et al.* 1980; Crosbie *et al.* 1987). In most conditions none are superior to the weighted disk. They are costly, less robust and more subject to variation due to prevailing weather and ground conditions. These problems off-set their major advantages which are:

- ability to repeatedly monitor a plot without disturbing the vegetation
- use on very stony paddocks or steep slopes
- facility for storing individual readings on the electronic data bank.

Even when extreme care is taken with waxing of the prongs, and having regard to weather conditions in relation to use and calibration of the meter, the results are often disappointing. The unquestioning acceptance of results from many of these (and other) meters is a problem.

2.5.4 Sward height stick

Sward height may be used as an index of pasture mass, and hence of animal production. Trevor Brown (South Australian Department of Agriculture, Kybybolite) and David Hamilton (Agriculture Victoria, Rutherglen Research Institute) used this approach, and recently it has been extended for use in pasture management by farmers in the UK.

The objective is to estimate the surface height of the green sward above ground and a simple device (Figure 2) is described by Barthram (1986). This consists of a 10 mm × 20 mm perspex plate which can be lowered until it touches the surface of the sward. Measurement with accuracy greater than ± 0.5 cm is considered to be unrealistic.

The heights obtained depend on the area of the plate, the uniformity of the pasture and the definition of 'sward height'. Brown and Hamilton used the height of the third leaf contacting the lowered plate or marker as the measurement of pasture height; Barthram (1986) and others record the height of the first contact with a leaf. The larger the plate the more likely it is that odd tall individual plants will be touched by it. Hamilton *et al.* (1976) have shown that **PM** can be estimated from pasture height, but the relationship varies with year, species and probably also with season.

Figure 2. The Hill Farming Research Organisation Sward Stick.

In Britain the Agricultural Development and Advisory Service (ADAS) produce a sward height record pad for use by farmers. The pad consists of a number of sheets for recording sward height (see example in Table 6). Measurements of sward height are entered in a table so that the frequency distribution of sward height can be seen.

Table 6. Example of a page from the ADAS sward height record pad.

ADAS instructions are to walk across the area to be measured in a W or zig-zag, measure height at regular distances (*e.g.* every 10 paces) and continue taking measurements until a regular pattern emerges. Recording sheets such as this could be used with the weighted disk pasture meter (2.5.2) to determine the required sampling effort for each plot.

The instrument shown in Figure 2 has been simplified. The sward stick produced by ADAS is a plastic rod with embossed marks and numbers. The rod is held with the thumb downwards, and the hand slipped down the rod until the ball of the thumb makes contact with a green leaf (Figure 3). Readings of sward height are made to the nearest 1 cm.

Note: The first line must be 0.5 cm from the bottom of the stick, and the numbers should be written upside down.

Figure 3. Simplified sward stick produced by ADAS.

2.5.5 Pasture-animal relationships

Pasture data are collected in grazing experiments to aid animal management or to explain animal performance. The simplest measurement is sward height or **PM** obtained at specific dates.

For a grazing period of t days, the mean $PM = \frac{PM_0 + PM_t}{2}$, where PM_0 is **PM** on day₀ and PM_t is the **PM** on day_t. For the weighted-disk method, the mid-period **PM** can also be calculated by taking the overall mean of the mean heights at day₀ and day_t and using the pooled regression from cuts at day₀ and day_t (see 3.1.1). This ‘smooths’ the data curve and allows growth rate and **PM** to be plotted on the same time scale. If the animals are measured at the same time as the pastures it is possible to examine relationships among pasture mass, green%, growth and animal production (see section 7).

3. MEASUREMENT OF PASTURE GROWTH

3.1 NET PASTURE GROWTH

Net pasture growth (**NPG**) is the difference between true growth and decay and may occasionally be negative (e.g. mid-winter). **NPG** can be estimated by assessing the change in herbage yield in areas from which animals are excluded for periods of up to 4 weeks by means of rotational grazing or pasture cages. However, the results may be biased because the areas are ungrazed.

A circular cage about 2.5 m in circumference made from welded wire mesh (e.g. 'Riverina mesh') makes a suitable enclosure to exclude the animals. Prongs on the bottom of the cage help to secure it in place. Allan Clark and John Graham of the PVI have designed a cage with a triangular profile; these stack for transport, and plans for their construction are available from the PVI.

The stackable cages must be pegged to the ground. This may also be required for cylindrical cages on pasture grazed with sheep where the pasture is short, if the ground is too hard to press the prongs into the soil, or where the mob is likely to blunder into the cages. All cages must be securely pegged if the pasture is grazed by cattle. The cages are shown in Figure 4.

For each period of t days, the **NPG** rate of pasture is taken as:

$$\frac{PMC_t - PMC_0}{t}$$

where $PMC_0 = PM$ in the cage on day₀ and
 $PMC_t = PM$ in the cage on day_t

In order to reduce the variance of estimating growth, the sites for measuring growth should not be chosen at random. If n cages are to be measured per plot, the area should be divided into n approximately equal areas and the cage positioned on a site that is close to the mean yield for that area.

The old approach is the matched-quadrat method (Lynch 1966). Pairs of quadrats at each site are matched at day₀ and one cut to ground level. At day_t the other, which has been protected by a cage, is also harvested and the difference represents growth. This is very time consuming and heavily dependent upon skill in initial matching.

3.1.1 'Hamilton method'

The method used at Hamilton is non-destructive and relies on the relationship between yield and the settled height of a weighted disk (see 2.5.2). A good procedure is to measure n sets of five points with the disk in each plot. (These data can be used to assess mean plot **PM**). The points of measurement are each marked with a wire pin. The pasture cage is placed over the pin marking the median height of each set (h_0). (The median is \approx mean, and since growth depends on how much leaf is present, it is important to account for this factor). After t days, the 'settled height' of the disk (h_t) is measured on exactly the same spot (Figure 4a). We are reducing variability by measuring the same plants (using a circular plate). This approach, analogous to a paired '*t*' test, will enable differences to be established which could not otherwise be detected either by matching or by using many more points set at random.

Figure 4. (a) Pasture protected from grazing being measured at a spot marked with a wire pin in order to assess growth.
(b) Cylindrical pasture cage.
(c) Stackable pasture cage.

Use the method described in section 2.5.2 (ii) to establish the relationship between settled height and yield at the start and end of each period. You should include some cuts from within the cages in establishing these regressions. This ensures that the population is adequately defined. Separate calibrations are required for plots or cages differing widely in composition *e.g.* clover or grass.

If the slopes and intercepts of the regression lines for day₀ and day_t do not differ, the growth of pasture in the cage is calculated from calibration data pooled from day₀ and day_t. This ensures that the calibration covers the growth period, and growth is calculated from the change in height of pasture in the cage.

Differences in calibration lines (meter reading *v.* pasture mass below disk) between periods or operators may be due to at least ten factors:

- (i) differences in technique in lowering the disk
- (ii) differences in settling time before the height is read
- (iii) area of pasture cut may vary depending on method used.
- (iv) disk weights may vary
- (v) dirt in dried pasture sample.
- (vi) pasture sample not fully dried before weighing.
- (vii) pasture roots included in cut pasture.
- (viii) pasture not cut to ground level.
- (ix) pasture composition different.
- (x) pasture structure changes (more stalky or lodged).

As with most techniques it is, therefore, important to adopt a scrupulously standardised approach to eliminate such problems. For best results one operator should take all readings, including those of the standards. Another person, if present, could move the pasture cages as required and cut all the standards.

It is important to always plot the data, for it is possible to obtain a spurious curvilinear fit when one or two ‘dodgy’ data are present.

For a linear model, if the slope of the pooled regression is ***b*** and the intercept is ***a***, then:

PM in the cage at day₀ is **$PMC_0 = a + bh_0$**

PM in the cage at day_t is **$PMC_t = a + bh_t$**

for the period day₀ to day_t :

$$NPG = PMC_t - PMC_0 = b(h_t - h_0)$$

$$NPG \text{ rate} = \frac{NPG}{t}$$

For the curvilinear model derived from pooled data:

PM in the cage at day₀ is **$PMC_0 = a + bh_0 + c\sqrt{h_0}$**

PM in the cage at day_t is **$PMC_t = a + bh_t + c\sqrt{h_t}$**

Using pooled data from day₀ and day_t

$$NPG = PMC_t - PMC_0 = b(h_t - h_0) + c(\sqrt{h_t} - \sqrt{h_0})$$

$$NPG \text{ rate} = \frac{NPG}{t}$$

The procedure described above should be used when the growth period is short (*e.g.* ≤ 4 weeks) and the morphology of the pasture is relatively constant.

When the day_0 and day_t calibration regressions are not similar (*e.g.* end of spring-early summer) then growth rate must be calculated using the separate regressions. Calculate PMC_0 and PMC_t , take the difference and divide by t .

It is not wise to continue measurements into summer - spurious data will be obtained, 'true' values are invariably zero, or near to zero (at least in the Hamilton environment).

3.1.2 How many cages are needed per plot to determine net pasture growth?

The question can be resolved by considering the accuracy required for the difference to be detected in relation to the precision of the measurement for a given pasture. You should estimate the s and then follow the method previously described for PM . We have done this for a situation at Hamilton (Table 7), using the falling disk method. The cage sites were selected as the median of five points at each site, in order to remove differences in PM as a major factor affecting NPG at that site.

Table 7. Number of cages needed to determine net pasture growth (NPG) rate at a range of pasture conditions and allowable errors (L)

Data from shelter experiment PVI (1980) where NPG is calculated from measured change in pasture height in cages over 28 days.

Period	Initial mean PM (kg/ha)	No. of cages	Change in height $\pm s$ (mm)	Mean NPG rate (kg/ha.d)	s	Observations required if $L =$			
						2	5	10	20
6/8 - 5/9	520	71	4.4 ± 4.1 (CV 93%)	8	7.5	57	9	3	1
5/9 - 3/10	840	69	8.2 ± 4.4 (CV 54%)	20	10.9	119	19	5	2
3/10 - 30/10	1160	52	24.6 ± 7.5 (CV 31%)	34	10.4	108	17	5	2
30/10 - 27/11	1460	57	41.2 ± 12.5 (CV 30%)	91	27.4	750	120	30	8

Note

- (i) It is clear that precision is not high (it is probably of the same order as that obtained from the matched cage technique) and one cannot justify reporting NPG to the first decimal place! No doubt the high s reflects large micro-site variation (fertility, pasture composition, etc.) as well as random error.
- (ii) Consequently it is not possible to determine NPG to narrow limits unless many cages are used, *e.g.* in spring about 30 cages are needed if $L = 10$, but in winter only three cages are needed.

- (iii) The data were obtained from uniformly grazed plots (up to 7 ha) at a high SR. It is likely that greater variability will occur at lower SR because the initial pasture height will vary more from cage to cage and this will affect growth.

3.1.3 How many cages are needed per plot to detect a significant difference in net pasture growth rate between two plots?

This problem is considered in Table 8 and is an extension of that considered in 3.1.2.

Table 8. Sampling required to detect pasture growth rate differences (D) between a pair of plots in 95% or 90% of comparisons ($P < 0.05$).

Precision of measurement (s)		Number of cages required at 95% (or 90%) level							
		D (kg/ha.d)							
		5		10		20		40	
Winter	7.5	60	(50)	17	(14)	-		-	
	10.4	115	(95)	30	(25)	10	(8)	-	
Spring	27.4	780	(630)	200	(160)	50	(40)	14	(12)

Note

- (i) Again, it is clear that we deceive ourselves when we put out a few cages and hope to demonstrate differences due to treatment! This is particularly evident in the spring (high growth rates). Also, one should probably judge the number of cages needed on the basis of treatment rather than plot size.
- (ii) When it is desired to detect small differences between treatments (*e.g.* 10 kg/ha.d) this will often require more cages than are available. Under those circumstances consider whether the objectives should be altered, whether experimental conditions could be changed to allow greater differences to be produced, or whether a more precise (albeit tedious) method is available. If not, then why waste time measuring *NPG*?

3.1.4 What about measuring *NPG* in replicated experiments?

In practice, mean *NPG* values from replicated treatments with fewer cages than suggested above may allow statistically significant results. Use the approach in section 2.2.3 to determine the appropriate number of replicates and intensity of sampling.

Consider the data from a PVI steer stocking rate experiment (Table 9). The *NPG* is for two periods corresponding to the winter 'low' and spring 'high' in Table 8. There were two replicates of each SR and four years of measurement (effectively eight replicates in the analysis for SR), and from three to seven cages were used on each plot. To reduce variability each cage was located at the median of five random points. In this analysis V_w for winter was 58 and for spring 751.

Table 9. *NPG* rate (kg/ha.d) of pasture in winter and spring as affected by stocking-rate (SR) of steers.

Date	SR (steers/ha)					Total			LSD (5%)
	1.2	1.8	2.4	3.0	3.3	Mean	V_b	variance	
30/7 - 27/8	21	14	10	11	12	13.4	26.9	47.1	7.2
2/10 - 19/11	72	78	56	55	43	60.7	107.2	618.6	14.4

From $SED = \sqrt{\frac{2(V_b + \frac{V_w}{n})}{R}}$ and $LSD = t' \times SED$

one can estimate the number of cages needed/plot (Table 10).

Table 10. How many replicates of each treatment and cages per plot are needed to detect a difference in *NPG* rate?

Estimated LSD (kg/ha.d) at 5% Level ^a										
Error <i>df</i>	Number of replicates (Block × Year)	<i>t'</i>	30/7 - 27/8				22/10 - 19/11			
			Number of cages/plot				Number of cages/plot			
			3	6	12	24	3	6	12	24
4	8	2.776	9.4	8.4	7.8	7.5	26.2	21.2	18.1	16.3
8	12	2.306	6.4	5.7	5.3	4.8	17.8	14.3	12.3	11.1
12	16	2.179	5.2	4.6	4.3	4.2	14.6	11.7	10.0	9.1
20	24	2.086	4.1	3.6	3.4	3.3	11.4	9.2	7.8	7.1

^a A difference between SR means is significant if it exceeds the **LSD** value in this Table.

Note that the real V_w for this experiment may have been less than assumed. It is clear, however, that differences between treatments will only be detected when more than three cages are used per plot where there are effectively only two replicates (within year) of each SR. Probably six cages are necessary but little is to be gained by further increase. A better prospect would be to increase replication while retaining the same number of cages used in the experiment.

3.1.5 Weighted assessments of pasture growth

All the examples outlined above assume that each cage represents an equal proportion of a plot. Occasionally it may be necessary to allow for factors that may affect pasture growth in different parts of a plot (see 1.3).

An extreme example was provided by Bird *et al.* (1994). The problem they faced was to estimate the effects of trees spaced at a range of densities on the growth of pasture between the trees. The pasture was regarded as being in a series of square cells, with a tree at each corner. Cells were selected at each density of trees, and seven wire pins located along a diagonal, one near the mid-point and the others distributed evenly on either side. The growth of pasture at or near these points was assessed for periods of 28 days using the weighted disk technique (see 3.1.1).

The measured values of growth across each cell were weighted to adjust for the proportion of the cell represented by each point. In cases where less pasture grows near trees a simple arithmetic mean of all seven points would not provide as good an estimate. The basis for the weighting system can be visualised by drawing circles of influence around each tree on the cell boundary, with radii midway between the seven sampling points. When this is done, four zones of influence (A,B,C and D) are apparent (Figure 5). If each cell has a side with a length (and area) of unity, the diagonal is apparent (Figure 5). If each cell has a side with a length (and area) of unity, the diagonal is $\sqrt{2}$ so that the pins are placed $\frac{\sqrt{2}}{8}$ units apart.

Pins 1 and 7 each represent 50% of zone A; pins 2 and 6 each represent 50% of zone B; pins 3 and 5 each represent 50% of zone C and pin 4 represents zone D. It may be calculated that weighting factors of 0.110, 0.196, 0.177, 0.033, 0.177, 0.196 and 0.110 apply for seven points spaced equally across the diagonal of a square of any size.

The average growth of pasture in the cell ($G_{avg.}$) is obtained by adding the products of growth detected at each pin and its weighting factor thus:

$$G_{avg.} = 0.110G_{pin1} + 0.196G_{pin2} + 0.177G_{pin3} + 0.033G_{pin4} + 0.177G_{pin5} + 0.196G_{pin6} + 0.110G_{pin7}$$

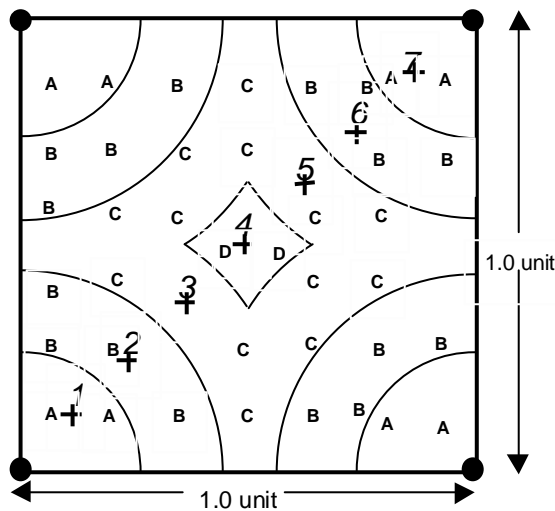


Figure 5. Zones of influence in a square cell of pasture bounded by trees.

3.2 TRUE PASTURE GROWTH

True pasture growth (**TPG**) is considerably greater than indicated by the **NPG** that we usually measure. There are two principal methods of measurement:

- (i) Marking tillers of grass and stolons of legumes and following length changes over short periods (Bircham and Hodgson 1983). The method is extremely labour intensive and requires concurrent estimates of plant density, mass and tiller and stolon length/weight relationships. If many species are present, the complexity of this technique probably precludes its use.
- (ii) Measuring **NPG** as well as the amount of decay of senescent pasture (**D**), or the change in green mass (**ΔG**) and the amount of pasture senescence (**PS**).

viz.

$$\mathbf{TPG} = \mathbf{NPG} + \mathbf{D}$$

or

$$\mathbf{TPG} = \mathbf{\Delta G} + \mathbf{PS}$$

A preliminary report of methods used to estimate **TPG** has been given by Cayley *et al.* (1980 a,b). The procedures are extremely tedious and subject to large errors; the least irksome and most accurate approach is to measure **ΔG** and **PS**.

There are instances where a knowledge of **TPG** is of interest. For example, the depressing effect on **TPG** of increasing stocking rate is much greater than indicated by the effect on **NPG** (Cayley *et al.* 1980b). We also find in winter that wet conditions lead to a substantial loss of dead pasture by decay and the small measured change in total **PM** during this time (**NPG**) is due to decay being balanced by the growth of new pasture (**TPG**). Thus, the proportion of green pasture rapidly increases over winter but the total mass increases slowly. This apparent constancy in **PM**, particularly in paddocks that have been lightly stocked and hence contain a large mass of dead pasture, may give the false impression that pastures do not grow in winter. The problem with using **NPG** as a meaningful measure of pasture growth is illustrated in the model developed by us from pasture and meteorological data at the PVI (see section 7). This shows the depressing effect of high rainfall in winter on **NPG**, consistent with the explanation above.

4. MEASUREMENT OF FORAGE SHRUBS

Forage shrubs, for example saltbush, bluebush or tagasaste constitute part of the feed-base for some grazing systems. Their forage mass can be estimated from the leaf area of the shrub or by the 'Adelaide' technique.

4.1 FORAGE MASS FROM LEAF AREA

The leaf area index (**LAI**) of a plant community is the area of leaves per unit area of soil surface. The **LAI** of a shrub may be estimated by means of a point quadrat (see also 5.2). We have used a frame consisting of a length of 25 mm diameter PVC waterpipe supported at each end by uprights mounted on stands. A length of bronze welding rod (1.6 mm diameter) filed to a point at one end is passed through holes drilled at even spacings through the pipe, and 'hits' on leaves (and stems, if that is required as well) are recorded as the rod is lowered vertically through the foliage. The horizontal pipe should be moved in order to assess several transects through each bush. If h hits are recorded from n pins then

$$LAI \approx \frac{h}{n}$$

This formula underestimates **LAI** to some degree if the leaf laminae are not horizontal, and an improved procedure (used for pastures, but impractical in this case) is to insert the needle at an angle of 32.5° to the horizontal (see 5.2).

Several individual leaves must be harvested and their leaf area and dry weight determined in order to calculate the forage mass per unit leaf area. Methods for measuring leaf area include sophisticated optical methods and scanning leaves to produce a digitised image which can be analysed using a range of computer software. However, a simple approach is to photo-copy a set of leaves to prepare a sheet of leaf shapes. These are cut out with scissors, weighed and their area calculated after weighing a similar piece of paper of known area. The leaves are dried and the mass per unit leaf area computed.

If the base of the shrub is roughly oval in shape a reasonable estimate of basal area can be made by measuring the short and long 'diameters'. The mass of leaves on the shrub is given by:

$$\pi \times \frac{\text{short}}{2} \times \frac{\text{long}}{2} \times LAI \times \text{mass per unit leaf area}$$

4.2 'ADELAIDE TECHNIQUE'

The 'Adelaide technique' of Andrew *et al.* (1979) is a non-destructive technique which is superior to the one outlined above. A 'unit' is first selected. This is a leafy branch of the species to be estimated. It should be 10% to 20% of average shrub size, and should be shaken to dislodge any loose leaves. Each shrub is then scored for the number of equivalent 'units' it contains.

The forage mass of the shrub can be estimated by multiplying the estimated number of 'units' by the forage mass of the 'unit'. This approach requires that the observer can accurately relate 'unit' forage mass to the forage mass of the shrub; *e.g.*, a score of 5 indicates that the shrub forage mass is exactly 5 times the mass of the unit. This may be sufficiently accurate if only approximate estimates of forage mass are required. At the end of the day the leaves are stripped from the 'unit', dried and weighed. If data on small

twigs are required, these will have to be treated similarly. If different species of shrub are being compared a separate 'unit' must be used for each type of shrub.

In practice, the forage mass of the 'unit' selected for scoring may not be typical of the shrubs being assessed, nor may the observer be able to accurately relate 'unit' forage mass to shrub mass. In the above example, a score of 5 may equate to a shrub larger or smaller than 5 times the 'unit' mass. For a more precise estimation of forage mass of a 'unit' equivalent, as applied to the shrubs being scored, a set of calibration shrubs should also be scored in the same manner by each observer. The calibration shrubs must be protected from browsing animals until the completion of the period of measurement when they are harvested and the foliage stripped, dried and weighed. The regression of forage mass of the calibration shrubs (y) on the number of 'units' (x) is usually a straight line passing through the origin. The slope of this line is the best estimate of each operator's impression of forage on a 'unit' equivalent. This, multiplied by the number of 'units' estimated for the shrubs assessed during the course of a session, gives a more precise estimation of forage mass than would be obtained by simply stripping the 'unit'.

4.3 SIZE OF SHRUBS

The size (volume) of shrubs can be estimated from measurements of their bases and height.

Two basic shapes are the hemisphere, used where radius (r) \approx height (h)

$$\text{Volume} = \frac{2}{3} \pi r^3$$

and the cone, when $r \neq h$

$$\text{Volume} = \frac{1}{3} \pi r^2 h$$

These formulae effectively account for all cases.

5. MEASUREMENT OF BOTANICAL COMPOSITION, PERCENTAGE GREEN, BARE GROUND AND PLANT DAMAGE.

If botanical composition varies over a paddock it is important to sample with the same intensity over the whole paddock, or to stratify the sampling (see 1.2.4), if an overall impression of the botanical composition is to be gained.

5.1 RECORDING OF PRESENCE

Simply recording whether a species is present (or absent) in a number of quadrats thrown at random will provide some information about the distribution of that species. The method is qualitative and has limited value for most agronomic work (Lynch 1966). The likelihood of a species being in a quadrat increases as the size of the sampling unit increases. If the quadrat is too big, the species will be present in all quadrats, and it will not be possible to show differences between treatments. The best way to arrive at an appropriate quadrat size is to experiment, and a simple method is to have the quadrat frame subdivided into smaller areas. Lodge and Gleeson (1984) used 1 m² steel mesh with either a 10 cm × 10 cm grid (100 cells) or 5 cm × 5 cm grid (400 cells) to estimate the persistence of lucerne. Using fixed pegs as a guide, the mesh was re-located in the same position in order to accurately assess changes in time. When they compared the regression of frequency on plant density, they concluded that for lucerne, 100 counts in the 10 cm × 10 cm grid gave a more precise estimate of density than 400 counts in the 5 cm × 5 cm grid.

As results are dependant on quadrat size, it is not possible to compare results measured on one area with those of another if quadrats of a different size are used. Discrimination between treatments is improved as the quadrat size is reduced, and the logical step of reducing this size to a point led to the development of the point quadrat (Levy and Madden 1933).

5.2 POINT QUADRAT

This technique is used to measure the leaf area index (**LAI**) of a sward. Details of the modern developments of the technique are given by Warren-Wilson (1959). Briefly, this involves recording the number of hits on vegetation made by a needle mounted on a frame and inclined at an angle of 32.5° to the horizontal as it is passed through the canopy to the surface of the soil. The needle should have a fine point as errors are very large if the thickness of the pin approaches that of narrow leaves (*e.g.* silver grass). If ***h*** hits are recorded from ***n*** pins, then

$$LAI = \frac{\text{area of leaves}}{\text{area of soil}} \approx \frac{1.1h}{n}$$

The method allows **LAI** to be estimated to within about 10%.

$$\text{Botanical composition in terms of area for each species} = \frac{100 \times \text{species hits}}{\text{total plant hits}}$$

If the needle is mounted vertically, the amount of bare ground can be estimated. If ***n*** pins are pushed through the sward, and ***b*** reach the soil surface with no hits on pasture, the percentage of bare ground is given by:

$$100 \times \frac{b}{n}$$

Recording hits with a needle is tedious, and it is simpler to use an optical method. A suitable instrument can be made from a 300 mm length of square tubing fitted with fine cross hairs at one end and an eyepiece (1.5 mm diameter hole) at the other (Figure 6). The sighting tube is mounted off-set on a metal rod which can be jabbed into the soil. The pasture is observed through the eyepiece and 'hits' on bare ground recorded. About 50 readings/plot or stratum (see 1.2.4) gives a repeatable estimate of the amount of bare ground. This is a useful way of assessing pasture deterioration which may be due to erosion, overgrazing, salting or disease.

Figure 6. Optical 'point quadrat' for measuring bare ground.

5.3 ROD POINT

The rod point technique of Little and Frensham (1993) offers a simple and rapid alternative to the point quadrat. A narrow rod which is sharpened to a point at each end is placed horizontally at random at a number of points in a pasture. The pasture species touching or closest to each end of the rod are recorded, and the number of readings for each species is proportioned over the total number of recordings to obtain the botanical composition. The authors suggest a 50 cm length of 8 mm diameter wooden dowel as suitable.

If information is also required on the relative abundance of (say) three clover cultivars, the cultivar closest to each end of the rod is recorded in addition to the plants touching each end. The additional information is thus obtained without having to increase the number of

rod placements. The technique has several points in its favour. It is rapid, there is no bias between different operators and neither special skills nor experience are required. The method is suitable for assessments on-farm, for pasture surveys and for assessing large-scale grazing trials.

5.4 COLLECTION OF PASTURE SAMPLES FOR HAND SORTING

A large sample should be taken from each plot. This should comprise a number of samples (say 50/ha) that are cut to ground level from small areas (c. 30 cm²) with shears. The method used is to walk through the pasture and cut the sample from near your toe every 20 steps. To avoid bias ensure that the same area, not the same amount of pasture, is cut each time, and that the same number of steps are taken between each 'toe-cut'. Procedures for sub-sampling and sorting are given in 2.3.2 and 2.3.3.

5.5 DRY-WEIGHT RANKING

The dry-weight rank (DWR) method of 't Mannetje and Haydock (1963) depends on the ability of the observer to rank the species present in a quadrat in order of dry weight.

Some training is necessary; clover v. grass comparisons are difficult and a common mistake is to over-estimate the clover DM component. Each operator should assess and harvest a few quadrats for sorting and determination of the DM of the species components. This will help in the subsequent visual ranking of DM. Any method that relies on visual assessment is subject to bias between operators, so if used in an experiment, every observer should observe every plot.

The procedure is to record the species that ranks first, second and third in each quadrat, and to multiply the proportion of first, second and third rankings for each species by 70.2, 21.1 and 8.7 respectively. (The multipliers were derived from a least-squares analysis of many sets of hand-sorted samples, using the constraint that the sum of the multipliers equals 100). These figures are then added to give the percentage of each species expressed in terms of dry weight.

The appropriate quadrat size is a compromise, as the chance of less than three species occurring in a frame increases as the size of quadrat decreases. On the other hand, for large quadrats (greater than 1 m²) it may be difficult to rank the species in order. At Hamilton we use a 400 cm² square quadrat and make observations on about 50 quadrats per hectare.

Table 11 depicts an example of the use of a recording sheet and calculations for the DWR method.

Table 11. Recording sheet for DWR method of 't Mannetje and Haydock (1963)

Species	1st rank	2nd rank	3rd rank	%DM basis
Ryegrass				27 ^a
Sub. clover				19
Capeweed				11
Phalaris				14
Poa annua				5
Onion grass				5
Erodium				6
Other leg.				1
Other grasses				8
Other weeds				3
Total	50	50	50	99

^aCalculation for ryegrass: $70.2 \times \frac{16}{50} + 21.1 \times \frac{9}{50} + 8.7 \times \frac{3}{50} = 26.8\%$

Initially, limitations to the DWR technique were that at least three species had to be present in every quadrat and that the highest possible estimate for any species was 70.2%. These problems are overcome if the method of cumulative ranking (Jones and Hargreaves 1979) is used. Their method involves, where necessary, recording more than one rank for a given species in a particular quadrat. Table 12 shows all possible ways that multiple ranks can be given to one or two species.

Table 12. Examples of cumulative rankings for the DWR method.

Quadrat	Species	Estimated proportion (percent)	Rank 1	Rank 2	Rank 3
1	A	70	1	1	1
	B	30			
2	A	79	1	1	1
	B	21			
3	A	91	1	1	1
	B	9			
4	A	100	1	1	1
	B	0			

If it is not possible to tell which of two species should occupy a rank for a particular quadrat, a tied ranking may be used and a count of $\frac{1}{2}$ given to both species. Similarly if three species are tied, a count of $\frac{1}{3}$ is recorded for each. An easy way to do this is to enter $\bar{2}$ for counts of $\frac{1}{2}$ or $\bar{3}$ for counts of $\frac{1}{3}$. This takes less space than writing fractions like $\frac{1}{2}$, and also may be less confusing when ties are entered with counting strokes (see Table 11).

Calculations can be done using a computer spread-sheet, but remember to give the correct values to the $\bar{2}$ and $\bar{3}$, that is $\frac{1}{2}$ and $\frac{1}{3}$ respectively!

Every combination for two or three ties is given in Table 13.

Table 13. Combinations of tied ranks (two or three ties) for the DWR method.

Tied ranks	Species	Rank 1	Rank 2	Rank 3
2 tied (no third species)	A	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
	B	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
2 tied for first	A	$\frac{1}{2}$	$\frac{1}{2}$	1
	B	$\frac{1}{2}$	$\frac{1}{2}$	
	C			
3 tied	A	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$
	B	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$
	C	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$
2 tied for second	A	1	$\frac{1}{2}$	$\frac{1}{2}$
	B			$\frac{1}{2}$
	C			$\frac{1}{2}$
3 tied for second	A	1	$\frac{1}{3}$	$\frac{1}{3}$
	B			$\frac{1}{3}$
	C			$\frac{1}{3}$
	D			$\frac{1}{3}$
2 tied for third	A	1	1	$\frac{1}{2}$
	B			
	C			
	D			
3 tied for third	A	1	1	$\frac{1}{3}$
	B			
	C			
	D			
	E			
2 tied for first and 2 tied for third	A	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
	B	$\frac{1}{2}$	$\frac{1}{2}$	
	C			
	D			
2 tied for first and 3 tied for third	A	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{3}$
	B	$\frac{1}{2}$	$\frac{1}{2}$	
	C			
	D			
	E			

The DWR method assumes that there is no association between **PM** in a quadrat and its botanical composition. If this is not the case, for instance if low yielding areas are dominated by clover and high yielding ones are dominated by grass, the overall proportion of grass in the pasture will be underestimated.

Jones and Hargreaves (1979) have shown that this bias can be eliminated if the **PM** in each quadrat is estimated in addition to ranking the species present. This involves very little extra field work, as **PM** is estimated (visually or by weighted disk) at the same time. Their method, illustrated in Table 14, involves multiplying the **PM** of each quadrat by the appropriate DWR multiplier for each component to give a weighted dry weight rank (WDWR).

Table 14. Botanical composition calculated by DWR and WDWR methods.

Quadrat	(a) DWR			PM t/ha	(b) Weighted DWR (t/ha)		
	Grass	Legume	Weeds		Grass	Legume	Weeds
1	0.70	0.09	0.21	2.4	1.68 ^b	0.216	0.504
2	0.70	0.09	0.21	2.7	1.89	0.243	0.567
3	0.21	0.70	0.09	1.8	0.378	1.26	0.162
4	0.21	0.70	0.09	0.9	0.189	0.63	0.081
Total	1.82	1.58	0.60	7.8	4.137	2.349	1.314
Percent	45.5 ^a	39.5	15.0		53.00 ^c	30.1	16.8

$$^a 45.4 = \frac{100 \times 1.82}{4} \quad \text{gives percent grass in area using DWR}$$

$$^b 1.68 = 2.4 \times 0.7 \quad \text{gives weighted rank for grass in quadrat 1}$$

$$^c 53.0 = \frac{100 \times 4.137}{7.8} \quad \text{gives percent of grass in area using WDWR}$$

In this example, the percentage of grass was underestimated if DWR was used because grass ranked first in the two high-yielding quadrats and last in the two low-yielding quadrats. Cumulative ranking and tied ranks may also be used in association with the WDWR approach. A repeatable estimate of botanical composition can be made by observing 50 quadrats on a reasonably uniform area.

These methods are incorporated in the package BOTANAL, developed by and available from the CSIRO Division of Tropical Crops and Pastures (Hargreaves and Kerr 1978; Tothill *et al.* 1978).

5.6 BASAL COVER

Bare ground or basal cover of species or group of species (*e.g.* clover, grass, capeweed) on small sown plots can be quantified by estimating the vertically projected ground % cover of each component to 10% units in a square quadrat (*e.g.* 30 cm × 30 cm). Minor species present in quadrats are given 2% or 5% cover. We use 5-10 quadrats per 20 m² plot. A convenient size is 30 × 24 cm, with sides and ends marked at 6 cm intervals to indicate cells of 5% area, or multiples thereof. This enables the operator to easily judge what area is represented by a particular species. The sum of % cover of component species will often exceed 100% due to foliage overlapping, so total cover must be estimated independently rather than by summation.

A Braun-Blanquet (1932) scoring system of cover abundance (Table 15) may also be used. There are many modifications of which three are presented.

Table 15. Modifications of the Braun-Blanquet cover abundance survey system.

Score	Species cover (%) in quadrat		
R	<1, solitary plant ^a		
+	<5, few plants	<1	<5, few plants
1	<5	<5	<5
2	5-20	5-25	5-20
3	21-50	26-50	21-50
4	51-75	51-75	51-75
5	76-95	76-100	76-100
6	>95		

^aSpecies found outside the quadrats are also given this score. The R and + categories denote species of restricted abundance.

This system is non-linear over the range and therefore scores cannot be averaged to give a plot value for a particular species.

This survey classification method gives greater emphasis to presence or absence of a species, rather than variation in quantity, and so is often used when the prime objective is to reflect an environmental effect responsible for vegetation change (*e.g.* soil type, frost, salinity, waterlogging, altitude or aspect).

5.7 INSECT, FROST, SALINITY OR HERBICIDE DAMAGE

The simple repeatable five-point scoring system illustrated in Table 16 can be used to assess damage by insects (locusts, grasshoppers, red-legged earth mite, etc.), frost or salinity scorch.

Table 16. Scoring system for estimating plant damage.

Score	Damage observed	Range of damage (%)
1	little or no effect	0-20 (mean 10)
2	intermediate between score 1 and 3	20-40 (mean 30)
3	half plants dead/half leaves dead or eaten	40-60 (mean 50)
4	intermediate between score 3 and 5	60-80 (mean 70)
5	plants dead/most leaves scorched or eaten	80-100 (mean 90)

A number of plants (or quadrats) are assessed in each treatment plot and independently scored. A five-point scoring system gives ample definition of the range and is easy to use. For one-off application, score 5 for the worst case and 1 for the least (usually nil) effect. Rank each plant or quadrat within that range (3 being intermediate). Record (preferably with photographs) what the extremes are. Repeat this process at each assessment date. The extremes may vary between dates but the records can be used to relate the two assessments.

The mean *score* for each plot is then calculated and may be expressed as a % *damage*, from the relationship of *score v. mean % damage* viz.

$$\% \text{ damage} = -10 + 20 \times \text{score}$$

The results are constrained in that calculated values cannot exceed 90% or be less than 10%. The precision of the method depends on the sample size (see 1.2.1 and 2.2.1).

We have found it satisfactory for estimating salinity scorch in plots having four or five seedling trees. If statistical analyses are done on *score*, it is not possible to calculate *SEDs* in terms of % damage because the line defined above does not pass through the origin. This is overcome if the % *damage* is calculated from *score* before the data are analysed.

6. MEASUREMENT OF SEED RESERVES IN SOIL AND PLANT DENSITY

6.1 SEED RESERVES

Seed reserves in soil are estimated by taking cores of pasture and surface soil. After threshing, the seeds are separated by processes of sieving, air-blasting or differential flotation using heavy solvents. For surface seed, carefully remove standing herbage then suck up the seed with a motorised vacuum.

Data for Hamilton from Paul Quigley of the PVI indicate that when 15 samples were taken from one 40 m × 40 m area on each of 16 farms, the mean seed count varied from 11-92 seeds per 154 cm² core. The *CV* varied from 45% to 126%, with the higher values tending to occur at lower seed density sites. If you require an estimate of seed density within 20% of the mean then 20-155 samples are needed/plot for the above example (see 2.2.1).

For replicated experiments the approach given in 2.2.3 can be used to estimate the required sampling intensity. An example for medic seed in 10 m × 2 m plots (five blocks of seven treatments, with four separate 10 cm diameter cores from each plot) is:

overall mean ± s	= 19.5 ± 13.8 seeds/core	(<i>CV</i> = 71%)
variance between plots (<i>V_b</i>)	= 86.4	(<i>CV</i> = 48%)
variance within plots (<i>V_w</i>)	= 154.4	(<i>CV</i> = 64%)

The estimated *LSDs* for a range of replications (*R*) and number of samples/plot (*n*) are given in Table 17.

Table 17. How many replicates of treatments and samples per plot are needed to detect differences in seed density between treatments?

Error <i>df</i>	<i>R</i>	<i>t'</i>	Estimated <i>LSD</i> at 5% level				
			Number of observations/plot				
			2	4	10	20	40
12	3	2.179	22.8	19.9	18.0	17.3	16.9
24	5	2.064	16.7	14.7	13.2	12.7	12.4
36	7	2.028	15.1	12.1	10.9	10.5	10.2

This example indicates the likely magnitude of differences that can be detected and it is clear that considerable replication is needed to detect small differences between treatments. The table indicates that increasing *n* above 10 confers little benefit.

For large plots it may be better to bulk together, say, 50 cores/plot and then use a sub-sampling process (see 2.3.2) to obtain duplicate samples for analysis. However, in bulking the cores you forfeit any information on *V_w*. The mass of the bulked cores before sub-sampling and that of the sub-samples before processing, must be determined in order to calculate the number or mass of seed per unit area of pasture. This approach assumes that the mass of each core is the same. The closest one can come to this in practice is to extract the cores to the same depth. The accuracy of individual cores in terms of the number or mass of seed per unit mass of soil will be seriously compromised if attention is not paid to this detail.

6.2 PLANT DENSITY

6.2.1 Counting methods

The choice of sampling unit (size, shape) is important - see 1.2.1. Also, note that quadrat size should be great enough to minimise occurrence of zeros; too many will result in skewed data.

The question of how many samples are required has been discussed in 2.2.1, 2.2.2 and 2.2.3. While a minimum sample quadrat area is desirable, it is better to have, say, 50 quadrats each 100 cm² than 10 each 1000 cm², even though twice as much area is assessed in the latter case. This is particularly true when the plant distribution is patchy.

Always consider the use of ranked quadrat sets (McIntyre 1952) to reduce the work load and improve precision (see 1.2.6).

An alternative approach has been suggested by Des FitzGerald (NSW Agriculture). This is to record the number of small quadrats or length of row corresponding to a fixed minimum number of plants to be counted. Des uses a quadrat divided into squares and counts plants in the squares on a fixed diagonal. If, for example, 10 plants are to be counted and the first square contained three plants and the second square five plants, all the plants in the third square would have to be counted and the density recorded as the total number divided by the area of three squares (provided of course, that at least two plants were present in the third square). The size of the squares will depend on the density of plants to be counted.

If establishment of pasture sown in rows is to be assessed, the length of row corresponding to a chosen number of plants should be measured and converted to plants per unit area before statistical analysis.

The variation in output between the metering devices on sowing machinery and the influence of the passage of machinery wheels on establishment (see 1.2.1), mean that sampling should be done perpendicular to the direction of sowing, in sets of rows equal in width to the effective sowing-width of the drill (see 1.2.1). Use a rod to mark the width to be sampled, then assess the length of each row required to record (say) five plants. This improves accuracy will be more convenient than using a rectangular quadrat with length equal to the effective sowing-width of the drill (see 1.2.1).

The 'FitzGerald method' has several advantages over counting all the plants in a fixed distance or quadrat.

- (i) The problems of skewed data are reduced.
- (ii) Time may be saved in the unnecessary counting of large numbers.
- (iii) Low densities are probably estimated with more precision.

When changes in density of species over time are required, then use a fixed quadrat or line (fibreglass rods make good markers) so that the same individuals are assessed each period. This is much more effective than using random quadrats at each period; many more samples are required with the latter approach. If plants develop tillers it will be impossible to identify individual plants. In this case persistence can be assessed by estimating changes in cover.

Lodge and Gleeson (1984) used steel mesh located at fixed points to measure changes in lucerne (see 5.1). They counted crowns in the squares of the mesh and found that they could reliably measure changes in time. They also assessed the relationship between

crowns as counted and the true number of plants by excavating the plants growing in the squares. Counts at the surface underestimated the true number of plants present.

In order to quantify the fall in plant density with time, either during a year for annuals or between years for perennials, plant numbers should be plotted on a log scale against time in years (Y). If the line is linear, the half life ($T_{1/2}$) of the population can be estimated (see Leach 1978).

$$\begin{aligned} \text{For example: if } \log_e (\text{numbers}) &= a - bY \\ T_{1/2} (\text{in years}) &= \frac{0.693}{b} \text{ (i.e. } \frac{\log_e 2}{b} \text{)} \end{aligned}$$

This is an excellent way of estimating the persistence of perennials (particularly those with limited seeding capacity) from short-term data and for comparing the performance of plants in different environments or management systems.

6.2.2 Distance method

With this approach one records distance between centres of a randomly situated pin and the nearest plant (see Pollard 1971). The process is repeated a number of times, n ; this value depends on our allowable error (see 2.2.1). If we want an estimate within 10% of true mean:

$$\begin{aligned} \text{then } L\% &= \frac{1.96 \times CV\%}{\sqrt{n}} \\ \text{so } n &\approx \frac{4CV\%^2}{L\%^2} = 0.04CV\%^2 \end{aligned}$$

The average distance (d) to the nearest plant from random points is:

$$\begin{aligned} d &= \frac{1}{2\sqrt{D}} \text{ where } D = \text{density (plants/unit area)} \\ \text{so } D &= \frac{1}{4d^2} \end{aligned}$$

Note that density must be calculated for each distance measurement. The mean density is then calculated. Do not estimate mean density from mean d .

An unbiased estimator of D can also be used:

$$D = \frac{n-1}{\pi \times (d_1^2 + d_2^2 + \dots + d_n^2)} \text{ or } D = \frac{n-1}{\pi \sum_{i=1}^n (d_i^2)} \text{ and variance} = \frac{D^2}{n-2}$$

Tom Morgan (Agriculture Victoria's pasture agronomist at Ararat), believes that the latter approach is quicker, easier and more accurate, but both methods tend to over-estimate density in communities of evenly spaced plants (*e.g.* crops, sown pasture) and under-estimate density where plants are randomly dispersed. Pollard (1971) warns that the method will give biased estimates when plants are not 'uniformly random', or when selected points are not truly random. When plants are closely spaced (*e.g.* subterranean clover seedlings) it is vital to record distances to the random pins accurately - *i.e.* to the nearest millimetre, not the nearest centimetre. Failure to do this gives nonsense results. An advantage of the linear method is that the sample size (*n*) does not depend upon the density (*D*), *i.e.* the same number of samples are required for sparse or dense communities.

6.2.3 Tiller density

Studies of swards of perennial grass often include assessments of tiller density, as it is generally impossible to distinguish between individual plants. Two main methods of estimating the density of tillers are used.

- (i) Counting the number of tillers in a small sub-sample (about 1.5 g dry weight) selected from herbage cut from within a quadrat (Jones *et al.* 1982). In this case, the herbage can also be used as an estimate of yield. Care should be exercised in taking the sub-samples. Use a quartering procedure (see 2.3.2). It also helps if the herbage is cut cleanly to ground level with no 'second cuts'. It is of course necessary to assess the dry weight of both the sub-sample and the remainder of the herbage from each quadrat in order to calculate the density of tillers.
- (ii) Plugs of pasture can be removed from each plot, and rooted tillers counted after teasing them apart. Mitchell and Glenday (1958) give the details of construction of a suitable sampler and discuss statistical considerations, including those of plug size and sampling procedures. The diameter of plugs varies from 75 mm (Fulkerson and Mitchell 1987) to 50 mm (Hume and Lyons 1993).

6.3 IDENTIFICATION OF INDIVIDUAL PLANTS

If it is desired to estimate the persistence of plants from establishment, and recruitment of plants either from seed or by vegetative means is likely, the plants to be counted should be identified by twisting a length of coloured wire around their bases. Seedlings can be marked with galvanized nails, colour-coded according to date of placing. The nails should always be placed on the same side of the seedling *e.g.* north. In practice, there are problems with lost wires and nails, particularly in grazed pastures.

The position of plants in relation to a fixed line can also be assessed using the plant plotter of Friend and Johnson (1988). This device consists of two spring-loaded retractable 3.0 m long tapes set in swivelling cradles mounted 1.0 m apart at either end of a metal bar. The bar is located in a fixed position by means of pegs that pass through the bar into metal tubes set permanently into the ground. When the position of a plant is to be plotted, a metal pin is inserted through a washer fixed to the end of each tape and positioned vertically over the plant using a 'bull's eye' spirit level attached to the handle of the pin. The reading of each tape gives the coordinates of the plant. Friend and Johnson showed that 95% of repeated readings fell within a distance of 5 mm and that deviations from this distance were attributable to displacement by the hooves of grazing animals when the soil was very wet. The plotter can also be used to fix the position of nails or twists of coloured wire, making these easier to find.

7. MODELLING

Measurement of mean temperature (T), rainfall (P), soil moisture, solar radiation and green pasture mass (G) can be used to predict growth. The Pasture Production Ready Reckoner (Bowman *et al.* 1985) predicts NPG for weekly periods.

A simple NPG model developed at PVI (Cayley and Bird, unpublished) is also instructive. It illustrates the primary significance of the magnitude of G (kg DM/ha), and the modifying effects of T ($^{\circ}\text{C}$) and P (mm), and interactions among these three factors, in determining NPG in any 4-week period. The variable $P(-)$, the rainfall in the previous 4 weeks, was also included and it improved the prediction of NPG by a small but significant degree. Variables in this model were included if not significant (T , \sqrt{T}), only when they were also present in significant interaction terms.

The following equation was obtained from 4 years (March 1975 to February 1978) of a steer stocking rate experiment at Hamilton:

$$\begin{aligned} NPG \text{ (kg/ha/d)} = & 153 + 0.196G - 13.78\sqrt{G} + 0.48P - 8.74\sqrt{P} + 0.41T - \\ & 31.95\sqrt{T} + 0.88P(-) - 0.011GxT + 3.048\sqrt{GxT} - \\ & 0.001GxP + 0.299\sqrt{GxP} + 0.000046PxTxG \\ & (r^2 = 0.71, \text{rsd} = 10.9 \text{ kg/ha.d, CV} = 53\%) \end{aligned}$$

A steer-pasture model has illustrated the importance of knowing the amount of green pasture present rather than simply the total pasture present (Bird *et al.* 1989). This enables a greatly improved prediction of liveweight gain under varying circumstances.

We have also shown that if the percentage of green pasture and total PM are known then it is possible to predict the digestibility of the pasture (Bird *et al.* 1980). These estimates are very close to the digestibility of pasture selected by steers, particularly at moderate-high stocking rates (Bird *et al.* 1984).

8. FURTHER READING

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10. ABBREVIATIONS

Abbreviations used are listed below. Technical terms are defined in the text.

ANOVA	analysis of variance
CV	coefficient of variation
df	degrees of freedom
DM	dry matter
DWR	dry-weight rank
EMS	error mean square (error variance)
L	allowable error
LAI	leaf area index
LSD	least significant difference
ms	mean square (component of variance in <i>ANOVA</i>) i.e. $\frac{ss}{df}$
NPG	net pasture growth
P	probability
PM	pasture mass (always expressed as dry matter/unit area)
PVI	Pastoral and Veterinary Institute, Hamilton
R	number of replicates
r	correlation coefficient
r²	coefficient of determination of regression
rsd	residual standard deviation
s	sample standard deviation
SE	standard error
SED	standard error of the difference between two means
SR	stocking rate
ss	sum of squares (of deviations from the mean)
t'	Student's 't'
TPG	true pasture growth
V_b	variance between treatments
VD	variance of the difference between two means
V_w	variance within treatments
WDWR	weighted dry-weight rank

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