THE BIOLOGY OF GRAZING MANAGEMENT

(Invited Paper)

F. H. W. MORLEY*

Summary

Grazing management is discussed in relation to water utilization, pasture subdivision, botanical composition of pastures and plot variation.

Water utilization is likely to be most efficient if rainfall is moderately high, especially if highly productive plant species are grown in highly fertile soils. Both heavy and light grazing pressure may reduce efficiency of water utilization. The amount of plant material grown per unit of water may vary far more than the amount of animal product per unit of plant material grown. Important advances may be possible if the growth-physiology of plants is synchronised with rainfall, but systems should be tested on a whole-farm basis.

Pasture subdivision may increase plant production but the value of such extra production is limited unless it can be used at times, such as late pregnancy, when nutrition is most critical, or unless it is used to increase stocking rates. The effectiveness of subdivision should depend on stocking rates, being highest at intermediate grazing pressures. Evidence on this point is not clear. Extrapolation from results of experiments on subdivision, using small plots, may not be valid for commercial paddocks, except possibly over short periods of time.

The botanical composition of a pasture may be affected by grazing pressure and management. Under heavy continuous grazing perennials will usually suffer, but this may not have serious consequences on pasture production. The value of perennials, ***vis a*** vis annuals, is open to some question and may vary greatly from season to season.

Plot variation may be generated because of a precarious equilibrium between grazing pressure and pasture growth. The most probable response to increased grazing pressure is a "crash" at some critical point, but averages over replicated experiments may obscure such responses. The importance of an understanding of causes of plot variation-edaphic, microclimatic and biotic-is necessary for application of results of grazing experiments to commercial production. Biology must not be subservient to the cult of statistical significance.

I. DEFINITION

Grazing management is considered in this paper as the control of pastures, and livestock and their movements, in a pasture ecosystem. It embraces control of the pattern of stock movements or grazing strategy, pasture management or the control of species, fertilizers, and agronomic practice, and animal management or the control of type of stock, and operations such as lambing or calving.

I consider the objectives of grazing management to be:

1. Maximum profits,
2. A stable biological system,
3. Minimum animal stress.

The objective is. not, for example, to make herbage production fit the nutritional requirements of livestock. We must understand that such an objective may at times run counter to the real objectives of agricultural practice.

*Division of Plant Industry, C.S.I.R.O., Canberra, A.C.T.

Various aspects of grazing management have been reviewed by many authors recently, including Arnold (1964), Campbell (1962), Heady (196 1) , MacLusky and Morris (1964), Moore and Biddiscombe (1964), and Wheeler (1962). In particular Williams (1964) has contributed an important review on energy flow and nutrient cycling in animal-plant ecosystems. I do not propose adding another review, but to touch on a number of topics which have perhaps received inadequate attention in the past. I will refer to aspects of water use, subdivision of pastures, the botanical composition of pastures, and variation in plot productivity.

II. WATER UTILIZATION

When water utilization is being discussed by field biologists and agronomists, thoughts usually turn to deserts or irrigation schemes. Neither of these is really very important to human biology. The greatest improvements in water utilization are likely to come from plant management and improvement in areas of moderate rainfall, for reasons to be discussed.

The basic parameters of water utilization are the amount of plant material produced and the amount of water required for this purpose. Animal production introduces a third parameter — or set of parameters if we consider the different forms of animal production.

We may write an equation for animal production (A) from water (W) and dry plant material (P) as follows:

$$W/A = (W/P) \times (P/A)$$

The first term on the right side is the classical Transpiration Ratio (Slatyer 1964). It may vary from 100 to 5000 or even more. For pastures, likely values, on an annual basis, are 3000 for native pastures and 750 for improved pastures.

Water falling on the ground either runs off, evaporates, percolates through the soil to join the ground water system or is used by plants. Maximum water use thus depends on high soil intake (penetration), protection of the soil surface, high moisture retention by the soil and the presence of plants which are capable of using water when it is available. Such plants must possess an appropriate root system, be supplied with adequate nutrients and be physiologically in tune with water availability.

The second term reflects the conversion of plant material to animal products. Plant material produced by water may be lost in respiration, blow away, burn, or be eaten by animals. The simplest way to minimise losses is to make sure that this material is eaten continuously (Davidson and Philip 1956) but without reducing leaf area to ineffective levels. This is seldom, if ever, practicable. Under very heavy grazing pressure plant growth may often be restricted and the soil exposed to the sun. Although all of P may be consumed, A may be unfavourably affected. Under light grazing pressure, much of P is wasted and A is usually well below maximum although W may be fully utilized. If plant growth is slight, because of competition for light, efficiency of water utilization will be low. Compromises are necessary.

Heavy grazing pressure may reduce water intake through compaction of the soil surface and much of the ground may be exposed to the sun so that direct evaporation is high. Plants may be made less able to use soil moisture because

leaf area is inadequate, and possibly because roots are reduced and are thus incapable of exploring the soil. On the other hand, the large amounts of excreta may improve the water retention properties of the soil and the fertility.

Light grazing pressure may favour a soil surface permitting high water penetration, and the soil surface may be protected from radiation. Nevertheless the total loss of water to the atmosphere may be high through transpiration. The curve of water use efficiency follows closely that of plant weight increment in relation to the leaf area index (Slatyer 1964; Totsuka 1963) if environmental conditions are suitable for plant growth and if nutrients are not limiting.

Unfortunately the incidence of rainfall is not always geared to the growth-physiology of plants or the requirements of animals. *Phalaris* pastures in winter-spring probably have transpiration ratios of the order 300-500; in summer they may range from 2000 to infinity. Summer rains are wasted because the physiology of the plant is geared to a Mediterranean climate. By contrast lucerne has been found (Morley and Axelsen 1965) to have a transpiration ratio of about 300 in summer (though higher values are more likely) but in winter this may be 1200 for a winter active variety, 2400 for a variety which is somewhat more dormant in winter. Transpiration ratios of 250 or less have been observed in actively growing crops, and values of 100 are theoretically possible (Slatyer 1964).

Exploitation of the growth potential of such contrasting species is complicated by the probabilities of rain at different times, the relative food values of different species in relation to animal requirements and questions of what happens to water that is not used. Problems such as "should species with markedly different growth rhythms, such as *Phalaris* and lucerne, be grown separately or together?" cannot, at present, be answered with certainty. Work is in progress to examine problems such as this.

Animal management may possibly be geared to take advantage of the extended growth potential. Thus, on the Southern Tablelands of N.S.W., pastures giving better weaner nutrition over summer might permit later lambing and perhaps higher stocking rates. With Mediterranean type pastures, there must be a compromise between early lambing, with its attendant risks to mother and offspring, and late lambing, with its weaner problem accentuated by drying-off of pastures. Species which use summer rains, such as lucerne, could permit alterations in the animal production system, such as later lambing, better weaners and summer fattening. Or, perhaps, pastures which retain better their nutritive value through summer and autumn, or cheap methods of conserving fodder, could solve the weaner problem and thus permit greater efficiency of animal reproduction, although at the cost of efficiency of water use.

McMillan (1965) has drawn attention to the water-cost of agricultural production. One kg of scoured wool requires over 5 x 10^5 kg water and 1 kg. meat some 10^5 kg water, under average farming conditions. The biology of water use by plants, and of plant material by animals, suggest that these figures could be greatly improved in higher rainfall areas.

TABLE 1

Effect **of** *rainfall and grazing management on wool production from water*

Annual Rainfall* mm	Pasture	P Kg/ha	A Scoured wool/ha	W/P	P/A	W/A
600	Native	2000	6	3000	330	10^6
600	Improved (moderate stocking)	8000	20	750	400	3×10^5
600	Improved (heavily stocked)	8000	60	750	133	10^5
400	Native	2000	5	2000	400	8×10^5
200	Native	500	1	4000	500	2×10^6

*1 mm rain/ha weighs 10^4Kg.

A native pasture with a 600 mm rainfall might produce 6 kg scoured wool per hectare*, W/P would be about 3000, P/A about 330 and W/A about 10^6. These figures are compared with others in Table 1.

Efficiency of water use decreases with increasing aridity largely, but not wholly, because most water which falls is evaporated directly. A typical W/P for arid areas would be about 5000 (Slatyer 1964), but much of the plant material produced is likely to be inedible and, coming in bursts following infrequent storms, is available in famine or feast proportions.

Thus W/P may be improved by better species and better plant nutrition. P/A can be improved by making better use of the plant material grown, with a resulting improvement in W/A. In arid areas, however, such possibilities are limited unless most of the rain which does fall can be concentrated on relatively small portions of the total area. But such hardly-won water would be used for drinking, or for production of crops for direct human use, not for production of animal food.

III. PASTURE SUBDIVISION

The merits of subdivision of pastures and the control of grazing by subdivision have been hotly debated for years. More heat than understanding seems to have emerged from such debates. Apart from the effects of management on botanical composition of pastures, to be discussed later, we need to consider the effects of management on plant growth and on animal welfare, and on the plant-animal dynamic association.

Rotational grazing is unlikely to increase plant growth appreciably unless grazing pressure is sufficiently severe to cause leaf area to be limiting on continuously grazed pastures. Restriction of animals to portion of the pasture may then enable a pasture to be extricated from its lowly productive repressed state.

We have found the growth rate of a *Phalaris* pasture in winter at Canberra to be approximately 10 kg/ha/day under continuous grazing, but some ***50%***

* 1 hectare = 2.47 acres.

higher under a nine-paddock rotational system. This seems to us an impressive achievement which must have important implications in animal production. But does it?

Assume that 100 kg of extra (above maintenance) intake is sufficient to produce an extra 1.5 kg wool and 15 kg liveweight increase, and that 0.5 kg is required to maintain a sheep. The rotational grazing system would produce, over 100 days of winter, an extra 500 kg/ha dry matter. Assuming all this were available to animals and that both pastures entered the spring in the same state, an extra 7.5 kg wool and 75 kg liveweight would have been obtained per hectare over the winter period. If the pastures were stocked at say 20 sheep/ha (maintenance level under continuous grazing), the gains per head would be 0.3 8 kg wool and 3.8 kg liveweight. In practice, benefits would probably be substantially less because of inefficiency in the process of replacing the body stores lost in the early stages of growth. During that period, rotationally grazed animals would be kept on a substantially sub-maintenance diet to enable the pasture to develop a leaf area sufficient for high production.

This benefit would probably be the maximum achievable from winter management of pasture in a Mediterranean environment. The average benefit would be less, perhaps much less, because of years with early-autumn "breaks" and subsequent ample winter feed from all systems, or droughts in which growth is approximately zero under any system.

These calculations show that, if there is to be substantial benefit from rotational grazing of Merino sheep in winter, it must come, not from increased production per head, but from increased carrying capacity. In addition, if sheep approach spring in somewhat better condition, presumably less vulnerable to diseases such as pregnancy toxaemia and more likely to provide the young lamb with an abundant supply of milk, benefits might be worthwhile.

Therefore, winter management is not likely to be worthwhile for dry stock or for cows or ewes which are not lambing in late-winter or very early spring, unless additional stock are carried to benefit from the products of management. Additional carrying capacity will be possible if winter production is the only important bottleneck. If this bottleneck is removed by management, some other limitation will be found, perhaps induced in part by the winter management technique which removed the winter bottleneck.

Contradictory results of experiments in grazing management are often explained by variations in grazing pressure. Only where pressure is severe enough to limit growth substantially for an important proportion of the year is management likely to be beneficial. This explanation appeals because it is plausible and seems to bring many observations into line. But I doubt if it is always correct.

Consider a limiting case where grazing pressure is so severe that insufficient plant material is produced to maintain the grazing animals, no matter what the system. In such circumstances pastures are likely to deteriorate steadily, leaf area will generally be inadequate and management cannot solve any problems. Ease the pressure on such a system and benefits might appear. Ease the pressure much further and they may disappear. Management may help in bad years at some stocking rates, in good years only at very high stocking rates. The

necessity for a range of stocking rates and years in studies on pasture management is widely appreciated, but interest will usually be greatest at intermediate grazing pressures where controls may have their maximum effect. This should be considered at the design stage of grazing experiments and also in the interpretation of results.

Grazing experiments must usually be done with small plots, for obvious reasons. Is extrapolation from such experiments to commercial areas valid?

A continuously grazed pasture under moderate grazing pressure is seldom, if ever, grazed uniformly. Portions are subject to severe grazing pressure; other portions may escape defoliation for much of the year. A fairly clear pattern can be observed at times, especially over areas with single watering points or marked topographical features.

Changes in botanical composition and yield may result and these can be progressive in time and space. Deterioration of productive capacity may follow. Such changes often take several years and are sometimes reversible by modifications in management, or by a series of favourable seasons. Short-term experiments seldom disclose such trends and hence they could be misleading, except for short-term prediction.

The time-scale of botanical or other deleterious changes is important in planning property development. If subdivision is necessary to prevent changes, and these can be remedied by modifications in management, it can be postponed during the early stages of property development when capital is usually limiting. On the other hand, subdivision may be necessary to control grazing during the early stages of pasture establishment. Once a stable and highly productive association has been achieved, subdivision may no longer be necessary.

Animals may respond unfavourably to some types of grazing management, as Suckling (1956) reported in New Zealand. Training of animals, and perhaps managers, could be a necessary part of a system.

We have become accustomed to didactic pronouncements on the virtues of systems such as rotational grazing or set-stocking. I trust these few thoughts about some biological variables will encourage understanding at the expense of dogmatism.

IV. BOTANICAL COMPOSITION

The lower the proportion of the plant community consumed by animals, the greater the opportunities for selective grazing and the more likely is botanical composition to be changed by grazing. Moderate continuous grazing pressure may cause profound changes in botanical composition. Heavy grazing pressure, especially if intermittent, may be compatible with botanical stability but perhaps not with high plant production.

In general it seems that continuous heavy grazing is detrimental to acceptable perennials, which are likely to be replaced by unacceptable perennials, annuals or bare ground. 'The effect on yields of replacement of perennials by annuals is by no means clear and is probably so dependent on local conditions that generalization would be inadvisable. For example, we have observed that very heavily stocked, continuously grazed *Phalaris*-subterranean clover pastures became dominated by annuals. These pastures actually yielded, in the spring of

1964, more than the rotationally grazed pastures, which contained higher proportions of the perennial. The rainfall pattern limited the growth of the perennials more than that of the annuals. The differences in amount of carry-over dry matter became important the following autumn. But, given a different and equally probable pattern of rainfall distribution, or lighter stocking rates, the picture might well have been reversed.

Annuals may also be especially vulnerable if heavily grazed at seeding or germination, but light grazing may be tolerated. Most annuals have evolved mechanisms such as unpalatable seeds, heavy production of seed and staggered germination, which enable them to withstand much abuse. Self-compatability, usual in annuals, in addition to their morphology, makes them well adapted to colonisation of sites where perennials have been weakened (Stebbins 1957).

Perennials are often, if not generally, assumed to be preferable to annuals as pasture plants, but the evidence favouring this assumption is most unconvincing. Certainly perennial grasses are an important component in the control of high-fertility-requiring weeds of genera such as *Cirsium* and ***Onopordium*** (Michael, private communication). On the other hand, annual species of legume have been used in the control of perennials such as ***Hypericum perforatum*** (Moore and Cashmore 1942; Morley 1961) and have virtually eliminated many native perennial grasses (Moore and Biddiscombe 1964). And while grasses have outstanding merits for erosion control (Costin 1964) the relative merits of annuals and perennials are uncertain.

Some species, of which certain varieties of lucerne are fine examples, are unlikely to persist under continuous grazing (Kehr ***et al.*** 1963) at high stocking rates. This is probably true of all grazed perennials, except perhaps some species with adaptations such as underground stems or storage organs and with vegetative reproduction. Couch grass (*Cynadon dactylon*) may be a good example.

The pasture management necessary to maintain a stable botanical composition will thus vary with stocking rate. If the pressure on the pasture is not great, at least for certain periods, no special precautions may be necessary. As stocking rates rise, some form of spelling, inferring rotation, will become increasingly necessary. Then a further problem may rear its head. At heavy stocking rates with rotational grazing, annuals may disappear from the pastures. If the important legume happens to be an annual, this could have serious and untoward effects.

V. PLOT VARIATION

Observations on replicated grazing experiments, our own and those of other workers, have forcibly demonstrated the extreme variation between plots treated identically. Within any experiment, extreme differences in animal production between plots are found at some stocking rates.

A heavily grazed pasture is in a rather precarious equilibrium. If the animals consume more than the pasture is producing, they will reduce it and eventually their intake to a new point of equilibrium between availability and intake. At this point, especially with sheep grazing, growth may be seriously limited by leaf area. Unless environmental conditions for growth change markedly for the better, the pasture will continue to be dominated by the grazing animal.

Should such a situation persist, the pasture must "crash" due to weakening of the plants. Removal of grazing pressure for a period would be necessary for recovery of productivity. Another pasture, although similarly treated, might be able to surmount the grazing pressure. A more productive equilibrium more favourable to the pasture plants and to the grazing animals is possible because the environment is slightly, but sufficiently, better. The "crash" is thus avoided.

Differences between plots in productivity must thus tend to increase if the grazing pressure is near a critical point, but not if well above or below such point. As a corollary, edaphic factors, aspect, species or management treatments are likely to have important effects if grazing pressure is near-critical, but not otherwise.

Grazing experiments thus tend to generate non-homogeneity because of the biological interaction of plant and animal. Comparisons lose precision at the very point at which they are most interesting. Moreover, means of several plots tend to obscure the occurrence of "crashes". A smooth response curve of means may be a wholly inadequate description of the true reponse curve ("true" in a biological sense) of a set of uniform plots exposed to a set of treatments. The series of "crashes" may, on averaging, give a nice, smooth, continuous, misleading, curve.

This dilemma has some important consequences for design, analysis and interpretation of experiments and for application on a commercial scale.

At the design stage, we must be doubly clear of objectives. If we wish to make inferences for a large region, we must be certain that the soils, pastures and animals adequately represent that region. If we deliberately choose a very uniform site, we must accept severe restrictions on extrapolation.

The most important comparisons will be at the critical levels of grazing pressure at which error variance will be maximum. Hence replication should be greatest at such levels and may be reduced, perhaps dispensed with, at other levels. Indeed, it is difficult to see what information some extreme treatments, such as very low stocking rates, contribute. If we have a good idea of where grazing pressure is likely to be critical, perhaps the whole of the experiment should be performed at and about that level.

At the analysis stage, averages and analyses of variance may, at times, obscure important principles. It could be an important result that a certain treatment (say 22 ewes/ha continuous grazing) produced a certain result (satisfactory performance, 100 kg wool, 16 lambs/ha) on one plot, whereas only 16 ewes/ha crashed badly on another. If we cannot explain such discrepancies, our understanding of the biology is incomplete, even if our mathematical models are esoterically the most satisfactory. Unless we understand what is happening, we can scarcely apply our findings to commercial problems.

Van Vleck and Henderson (1965) have emphasised some limitations of blind faith in statistical tests. I cannot resist quoting from their paper. "With enough observations true correlations as low as 0.01 can be found statistically significant . . . Yet what is the biological importance of such a correlation?" "Certainly some knowledge of the magnitude of differences among treatment effects is more valuable than a test of the null hypothesis at some probability level".

There are many germs of wisdom in that paper; as biologists we should all profit from it. In particular we should recognise the role of statistics as a servant to biology. The biologist must ask the right questions; ones which are important and answerable. Statistics can help in design and analysis so that, with a given amount of material and effort, important errors (Type I or Type II) are minimised. It is the responsibility of the biologist, not of the statistician, to decide the probability levels he will accept. "The all-powerful cult of the significance test . . ." must give way to an appreciation of the biological system and of the economic consequences of different types of error.

Grazing management studies are often difficult and time consuming. Some are almost as expensive as recently developed types of laboratory biology. Hence the kinds of design and analysis, the types of errors and their consequences should be subject to fresh thinking rather than acceptance of the formulae derived for use in small plot studies. But let us not throw out the baby with the bath water.

In application, frequently indeterminate results must mean that blanket recommendations cannot be given for regions or for farms, or even for individual paddocks on farms, unless we understand the biology and can measure the important variables. In effect, the individual farmer must adopt an experimental approach and, appreciating the nature of the response curve, learn to recognise the symptoms of critical grazing pressure. For this reason, many small regional experiments, though invaluable for demonstration, may be of limited value as indices of regional potential productivity. Perhaps sets of meteorological tables would be more useful if we understood the biology.

VI. CONCLUSION

The topics considered here — water utilization, subdivision, botanical composition and plot variation — serve to present a limited array of ideas and principles. Some of the hypotheses suggested have been the subject of extensive experimentation. Clear conclusions are rare. I have endeavoured to show why results must often be indeterminate, why there is no room for didactic statements.

The most important conclusion emerging from these considerations seems to me to be the necessity for studying the biological complex as a whole, preferably on a large scale as well as on a small scale. This is not to say that pasture experiments without animals, or *vice versa,* are meaningless. But such experiments should be designed and interpreted without losing sight of the biological factors operating and interacting. To overlook the system as a whole is to invite incorrect interpretation and invalid extrapolation.

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