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STABILITY AND PRODUCTIVITY OF PASTURES

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SUMMARY

An analysis of some data from a replicated grazing experiment disclosed large variations among plots treated alike. Plot liveweight means in July appeared to have a bimodal distribution. The significance of such plot variation to economic analysis, and to the objectives of grazing experiments, is discussed. It is concluded the determination of an optimum stocking rate may be an unrealistic objective. The importance of studies of the symptoms of above-optimum grazing pressure is stressed. A policy of farm development and management decision-making is proposed for situations in which information on site productivity is inadequate.

Pastures are seldom in a state of equilibrium. Either the grazing animals are consuming more than that provided by net carbon fixation, or they are consuming less. The amount of pasture material on offer must thus be constantly decreasing or increasing. This is obvious.

Stability of pasture production may be defined as the ability of pastures, and animals grazing them, to maintain high levels of production over long periods despite variations in the environment. This distinguishes such stability from systems of land use such as crop production. Cropping is usually designed for very high levels of production, but over only brief periods. Regular interference by man, for example for ploughing, sowing, and harvesting, is necessary because the system is not stable in a biological sense.

In this respect, crops differ from grazed pastures in which, as will be discussed later, some stability of the ecological complex is an essential component in continued productivity.

In this paper, some results of a grazing experiment are examined with particular relevance to the maintenance and breakdown of equilibrium in a productive system.

SOME EFFECTS OF STOCKING RATE AND SUBDIVISION

As an example, the body-weights in late July and late November, 1964, 12 sheep per plot, 3 plots per treatment, from portion of one of the experiments at Canberra, are shown in Table 1.

TABLE 1: MEAN LIVEWEIGHT (KG) IN 1964, MERINO EWES

Month	Treatment	Stocking Rates (Ewes/Acre) 5	6	7
Late July	Continuous grazing	47	39	37
	3-paddock system	47	44	42
Late November	Continuous grazing	52	49	48
	3-paddock system	53	52	52

The analysis of variance of these data is given in Table 2.

TABLE 2: ANALYSES OF VARIANCE OF PLOT LIVEWEIGHTS (KG^2)

Source	d.f.	Mean Squares July	November
Stocking Rates ...	2	1,140*	123*
Treatments	1	532	357**
SR × T	2	161	88
Plots in SR × T	12	223	33

(* = P<0.05) (** = P<0.01)

The conventional conclusions from these results would be that the three-paddock rotational system had reduced the severity of the decline in July body-weight, probably through autumn-winter saving, thus enabling the higher stocking rates to be maintained with less risk. The November liveweights show that compensatory growth had taken place, so there was then little difference between treatments.

Only the stocking-rate effects are significant at $P=0.05$, but the management treatments look reasonable, are in line with accepted ideas, so they may be accepted as real. It is concluded that subdivision is unlikely to be worth while at stocking rates of less than six ewes per acre.

There are reasonable arguments. One expects a more-or-less linear response to increased grazing pressure. Economic analyses can be set up which assume linear relationships; these are simple to handle, and lead to recommendations for optimum stocking rates for regions in question.

A more penetrating analysis, however, leads to some more interesting and disturbing conclusions. If the data are analysed on an individual sheep basis, it is found that the mean square within plots is only 21 for July and 29 for November, with 198° of freedom. In other words, there were very substantial differences among plots treated alike, but only in July, and these differences caused the low significance of the stocking rate and treatment effects in July, despite much greater treatment differences.

The components of variance which are given in Table 3 illustrate this point.

TABLE 3: COMPONENTS OF VARIANCE (KG^2)

Source of Variance	*July*	*November*
Sheep	21	29
Plots	17**	0
Stocking rate × treatment	0	18
Treatment	34	36**
Stocking rate	153*	15*

(* = P<0.05) (** = P<0.01)

If separate analyses of variance of the July figures are performed, within stocking rate-treatment groups, *F* values as shown in Table 4 are obtained.

TABLE 4: ANALYSES OF VARIANCE WITHIN GROUPS FOR JULY — F VALUES

(d.f. among plots=2; among sheep in plots=33)

Treatment	*Stocking Rate (Ewes/Acre)*		
	5	*6*	*7*
Continuous grazing	5.6	16.3	35.4
3-paddock rotation	5.8	5.3	5.3

It is obvious that variation among plots treated alike is a function of stocking rate under continuous grazing, but not under rotational grazing. This is shown by the distribution of plot means, presented in Fig. 1.

The distribution of liveweights in July is not unimodal. Three means, two at seven ewes per acre, one at 6 ewes per acre, form one group. The remainder form another. The three-paddock system weights seemed normally unimodal.

These figures indicate a threshold of response. Once liveweight falls to a certain point, it appears to plunge. In other words, responses are not really linear.

The experiment has disclosed two important facts. First, pasture productivity was high in some plots. This fact gives an indication of a level of productivity which might be achieved if certain limitations were removed. This is not necessarily a maximum for the region and may be far below a maximum. The performance of the animals in question on a particular plot is an inescapable fact, not an estimate with an error term.

Secondly, some plots were poorly productive, well below others treated similarly. This suggests that one or more limiting factors have operated to cause a crash. In other words, the forces which tended to maintain high body-weight have failed, and a progressive worsening of body-weight has followed.

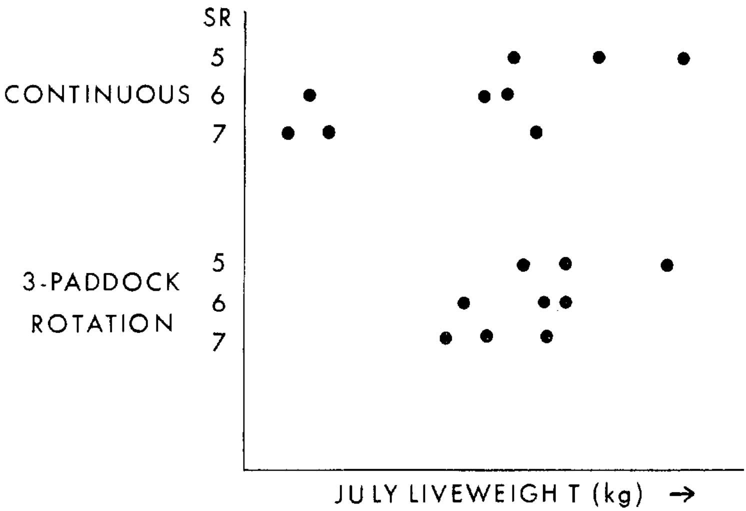

Fig. 1: Distribution of plot means — July liveweight.

If this is a general picture, then an average response, such as might be estimated from a normal replicated experiment, effectively conceals much of the biological information present in the experiments. The figures in Table 1 do just this.

It seems that a true response of animal performance to stocking rate is not linear. Animal performance may fall rapidly after a certain grazing pressure. At this "crash-point", only an improvement of the environment, such as higher temperatures, or removal of grazing pressure, can enable the pasture to extricate itself from its unhappy and unproductive state.

Of course, a small sample of plots is involved in this example. But further experience has suggested that the example is reasonably representative of a general situation. Moreover, similar "thresholds" seem to apply to traits such as wool production and reproductive performance. The picture is one of certain plots doing much better, or much worse, than the general average, as a critical stocking rate is approached.

If the true response to stocking rate is not linear, and if differences among plots treated alike are very large, one must recognize some important limitations of such experiments as indicators of optimum stocking rates, and management requirements at any given stocking rate, in the district in question.

First, an average response is a concept which, although perhaps useful on a national scale, has very limited value in a particular situation. Even on the national scale the presence of so much plot variation suggests that general conclusions may not be justified, unless the experimental area has truly sampled a large range of environments present in a region which is sufficiently large to be nationally important. This is seldom true.

Secondly, any farm, or paddock on a farm, may be subject to grazing pressure such that it hovers on the brink of a crash, without any recognized symptoms of danger being clearly observable. If this is so, it provides good justification for conservative stocking. Unfortunately, conservatism in stocking could cost the individual, and the nation, a great deal of production.

These difficulties suggest that the true problem facing farmers and their advisers is the recognition of impending danger. The ecology of "crashes" needs to be known so that they can be guarded against, and the causes rather than the symptoms treated.

As a first step, the conditions which seem likely to promote stable and high production, and those which might disrupt production and stability, can be listed. At the same time, it must be recognized that high pasture production at a given time is probably the main factor promoting stability at that time, but not necessarily at any other time.

THE STABILITY OF PRODUCTION

The main stabilizing and disrupting variables are listed in Table 5.

Most of the items listed will have obvious effects which need not be discussed in detail. However, a little elaboration may be useful.

TABLE 5: FACTORS INFLUENCING PASTURE STABILITY

System	*Stabilizing*	*Disruptive*
ANIMAL PHYSIOLOGY		
Maintenance requirements	Body-condition	Stress
Growth	Compensatory	Development
Reproduction	Response to nutrition	Demands
Reserves	Use when needed	
PLANT GROWTH		
Radiation	Optimum L.A.I.	Over-utilization
Water	Optimum L.A.I.	Evaporation, run-off
Nutrient cycling	High utilization	Under-utilization
Carry-over feed	Moderate levels	Too much
ECOLOGY		
Stand density	Full occupation	Open space
Longevity	Perennials	Annuals (?)
Species	Non-specialized	Special requirements
Mixture	Complex	Monospecific
Soils	Conservation	Physical and chemical losses
Animal behaviour	Controlled grazing	Selective grazing
SITE FEATURES		
Aspect	Growth promoting	Growth retarding
Fertility	High	Low
Water relations	Good	Poor
Topography	Even	Uneven

ANIMAL PHYSIOLOGY

If grazing pressure is severe, the grazing animals will lose weight and metabolic requirements should decrease. However, recent work by Lambourne and Reardon (1963), and by Arnold *et al.* (1965), suggests that requirements may actually increase, in some situations, as body-weight decreases. This then could precipitate a run-away from equilibrium.

Under light grazing pressure, a resulting high plane of nutrition, at certain times of the year, could well increase the reproductive rate, and hence the demands on the pasture. As a corollary, a low reproductive performance, induced by poor nutrition, could alleviate grazing pressure. The demands of reproduction could thus adjust discrepancies between plant production and animal needs, or alter animal numbers so that fuller use is made of plant production.

Reserves of protein and energy in animal bodies can be powerful promoters of stability in the system, especially in highly variable environments. They may, however, be very expensive in terms of productivity of the system.

Plant Growth and Animal Consumption

Davidson and Philip (1956) described relationships between the leaf area index (L.A.I.) and growth rate, and suggested that maximum pasture production would be obtained by a system of continuous defoliation which kept L.A.I. near optimum. In practice, this might be possible if sufficient animals were put on to the pasture so that, at L.A.I. corresponding to maximum plant production, growth exactly balanced animal consumption. Actually this equilibrium is not stable if the curve relating animal intake to L.A.I. rises either more or less steeply than that relating pasture growth to L.A.I. Possible relationships are illustrated in Fig. 2.

A stable equilibrium can exist at L.A.I. above optimum, but not if L.A.I. is below optimum, especially if sheep maintain maximum intake at availabilities well below the 1,500 kg/Ha of dry matter at which L.A.I. is likely to be

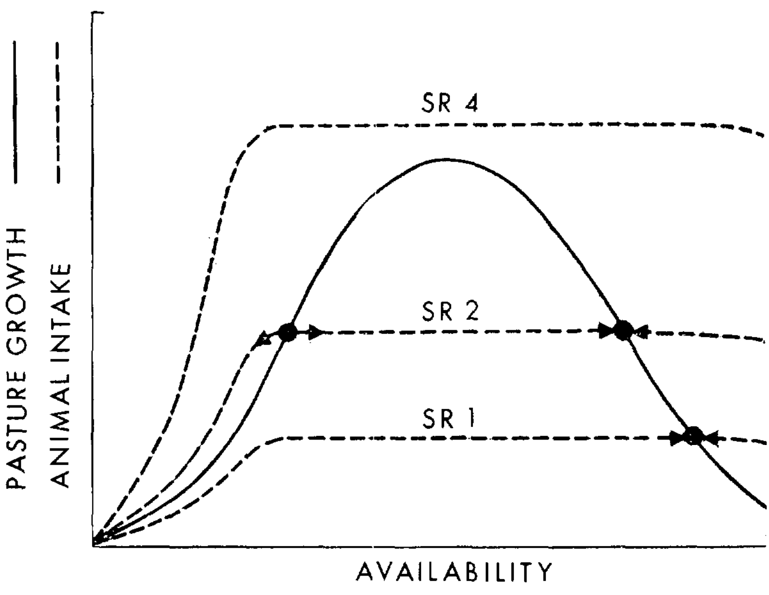

Fig. 2: Effect of stocking rate (SR) on pasture growth and intake.

near optimum. From the results of Arnold *et al.* (1965), this seems highly probable.

It may well be that on some kinds of pastures the left part of the plant growth curve could almost correspond with the intake curve at a certain stocking rate. In this case, an unstable equilibrium could exist over a range of availabilities and levels of animal production. Small changes in pasture growth rate or animal demand would swing availability either to right or to left.

Maximum production of pasture is therefore not possible under continuous grazing, if only because of this instability. But that is not to say that other systems are better.

Efficiency of water utilization will be similar to efficiency of use of radiation in relation to L.A.I. (Slatyer, 1965) and again the system is likely to be unstable except at above optimum levels of availability.

Under heavier grazing pressure, the turnover of plant nutrients is likely to be greater, giving effectively higher levels of fertility (McLachlan and Norman, 1966). Whether this is actually so is as yet uncertain, and difficulties of investigation are considerable, especially in view of the unevenness of distribution of recycled nutrients (Hilder, 1964).

Moderate levels of carry-over dry feed in summer, or autumn-saved green feed, can contribute greatly to stability. But too much carry-over may indicate wastage from under-utilization and cause shading of young pasture. More investigations are needed on the effect of this form of conservatism on long-term production of pastures.

Ecology

Stability, at least in high rainfall situations, is likely to be promoted by high stand density, which promotes resistance to invasion by unproductive species. However, the level of production achieved by the stable pasture may not always be high. Perennials will usually confer stability, but only if the environment can support them, and their requirements are not too specialized. A complex mixture may be a more stable producer of feed than a monospecific pasture, but complexity itself introduces problems of instability owing to variations in competitive ability among component species.

Conservation of the soil is, of course, a most important facet of stability. Overgrazing is the conventional villain to be blamed for much soil loss. It should not be confused with overstocking for, although overstocking may be a major contributor to overgrazing over large areas, overgrazing over small areas may be a feature of even light stocking rates. High soil fertility and dense surface cover are prerequisites for conservation of the soil. Some form of management may be necessary to maintain the stable situation.

Many natural plant communities are highly unstable. They may be altered radically by uncontrolled and selective grazing. This is especially evident in some semi-arid communities in which many species disappear rapidly following the introduction of domestic animals (Moore and Biddiscombe, 1964).

CAUSES OF PLOT DIFFERENCES

The classification and listing of all the variables of Table 5 serve as a starting point to investigations into the reasons for failure of three plots in the continuous grazing treatment.

No clues were found to suggest that animal physiology was involved. The plots had not suffered from high reproductive performance, and liveweights during spring and summer were satisfactory. The plots differed in aspect and topography, in soil types and stand density. Soil phosphate seemed unlikely to have been limiting. Other nutrients, especially nitrogen, may have been. But why on these three plots and not others?

There was, apart from the liveweight of the sheep, one common symptom. This was the low availability of pastures, presumably reflecting poor plant growth, on these three plots during the winter months. This was also true in some other months. It also seemed significant biologically, though not statistically, that plots in the three-paddock subdivision treatment did not break down. Further, the plot at seven per acre, and at least one of the two at six per acre, which did not crash, were on sites which seemed to favour high productivity — deep soil, high fertility, even topography and dense pasture.

The syndrome of plot failure is thought to have started in poor pasture growth, caused by limitations which may have been different in each plot, but which resulted in a run-away from stability, and a breakdown of the production processes.

Rainfall was inadequate for substantial pasture growth in 1964 on this experiment until late April. Prior to then, the sheep had remained alive on dry feed from the previous spring. The "opening" rains were followed by cold weather which restricted plant growth severely. On the problem plots, growth was insufficient to increase the amount of freshly-grown dry material beyond that needed to barely maintain sheep alive. The grazing pressure was such that a leaf area adequate for a growth rate high enough to enable sheep to increase liveweight, or maintain a high liveweight, did not develop until spring. On other plots, sufficient leaf area was produced to enable the pasture to escape from its poorly-productive state.

The effect of subdivision, if real, on production was apparently sufficient to extricate the pasture from the high-grazing pressure, small leaf area, low-production status. This is fortunate, and to be expected from Brougham's (1956) analysis. However, some of the unpublished results indicate that the benefits of subdivision in winter may be nullified, or more, by consequent adverse effects at other times.

GENERAL CONCLUSIONS

Experiments such as that which provided the data analysed here usually have the explicit or implicit object of determining an optimum stocking rate for a particular situation. Frequently, such experiments are not replicated. If the purpose is to establish a response curve, replication may not be necessary, but a large number of plots will be.

The analyses have shown the importance of site productivity in an area which, although not uniform, is not unusually variable. The writer is aware of similar variation in other experiments. Does such variation affect the validity of the objectives or designs? One is compelled to admit that it must.

A response curve to stocking rate, such as might be calculated from the data presented, is of little or no interest unless it can be used as a basis of economic analyses, and of recommendations to farmers. The variation demonstrated becomes so large as stocking rate becomes critically high that actual plot production may provide a less useful guide than would a set of meteorological tables.

An economist may use the curve to calculate an optimum or a response for a region, but these would be valid only if the various types of plot features were included in the experiment in approximately typical proportions. It is not clear how such analyses would be useful. Were the curve to be used as a basis of recommendations to individual farmers, without confident identification of the causes of variation, it could be grossly misleading.

A further difficulty arises from the fact that areas of vastly different potential would often be found within the one paddock. In the experiment, large differences in productivity were observed within a few hundred yards. The effects of such heterogeneity on long-term productivity under commercial-scale grazing is at present a matter for guesswork. It is possible that, on a large scale, processes which cause a progressive run-down may be modified by relief from grazing pressure through higher availability in adjacent, perhaps more productive, portions of a paddock.

Analyses such as that of Table 2 effectively obscure a great deal of information. They may be perfectly valid, for example, for variety trials for regions, provided the trials are conducted over an adequate and representative set of locations. They are of little use in most grazing trials, for these cannot be conducted at many locations. And the excuse that an experiment is replicated in time is invalid if plot variations reflect permanent features, which is true of those in the experiment over several years.

The determination of an optimum stocking rate for a region is thus impractical in the present context of finance for agricultural research. Moreover, it seems to be an objective of little value except perhaps to macro-economists, and even they would seem to risk too many unknowns in accepting results from one experiment.

What objectives might be reasonably valid for experiments in grazing management?

First, the effects of various forms of grazing management on productivity, and on soils and pastures, need further examination in a range of natural and imposed environments. Results are likely to be indeterminate if sensitivity is not assured by careful selection of matched sites.

Secondly, the symptoms of above- and below-optimum stocking rates require to be known. These symptoms may include animal and plant criteria. The criteria may come to be recognized asymptotically. They must be calibrated with economic analyses. This may not be such a difficult task if criteria such as July liveweight are found to be diagnostic, and to have non-continuous distribution. Criteria such as the amount of soil cover in December could be more important in the long term than any data from animal-plant production.

Thirdly, methods for assessing site productivity must be developed without the use of grazing treatments. This can be done only by intensive study of pastures under grazing, and by careful choice of treatments and sites to be tested. This is an imposing task, but one which is necessary if recommendations are to be soundly based.

Fourthly, the biology of grazing management, including nutrient cycling, plant physiology, water relations, and soil biology, still presents many blank pages. An understanding of these must be basic to the logical development of better management systems, the selection of better varieties of pasture species, and to conservation of resources. Again, the grazing animal is a necessary component of the complex.

These are perhaps worthy, but certainly long-term objectives. They enable advisers to tell farmers that much more research is necessary before advice can be given with safety. So the researcher is left with an interesting long-term project, and the farmer can manage somehow.

It is not surprising that the more progressive farmer decides to take matters into his own hands. He makes a few plausible assumptions. As a result, in one region one finds a cult of subdivision and rotational grazing; in another region, set-stocking is the catch-cry.

It seems that the scientist, ignoring cults and catch-cries, must devise some systems of grazing management which, while minimizing expenditure on improvements and pratices which are of dubious value, yet introduce an element of stability into the system.

Thus, a moderate amount of subdivision, which need not be costly, appeared to prevent "crashes" in the experiment described. There is no evidence to suggest that further subdivision would be appreciably better. There is some which indicates the contrary. Similar stability may be provided by relatively small investments in fodder conservation or extra fertilizer, but one must be clear on the actual cost of such measures.

Plunging too rapidly into near-limiting grazing pressures must also be avoided. Usually, it will be economical to hasten a little slowly, watching for danger signals as pressure is increased, and retreating when these become evident. Measures such as these may not appeal to the venturesome. But it is well to recognize the fact that the retreat from stability is progressive in time. It may also be progressive in space. Extrapolation from small experimental plots to large commercial areas involves reduction of homogeneity of the unit. Progressive deterioration on a small plot may not spread far. But progressive deterioration of a large unit may engulf the whole area. Thus, the chances of a crash on a large unit could be greater than those on a small unit, but they will depend on the grazing pressure.

Finally, while recognizing the presence of dangers and difficulties, one should not lose sight of the fact, demonstrated by most grazing experiments, that good pastures are capable of levels of production which were almost undreamed not many years ago. The task is to make sure that this level of productivity is used, and that its potential remains.

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DISCUSSION

A. G. CAMPBELL (COMMENT): We have found that the relation between grazing pressure (defined as stock grazing days/unit of available D.M.) and stocking rate is curvilinear. At high stocking rates, small differences in pasture productivity can thus cause large differences in grazing pressure at the same stocking rate. At times of declining pasture production, the differences in grazing pressure will increase rapidly. This could partly explain the bimodal distribution of body-weight found at the same stocking rate in winter.

DR F. H. W. MORLEY: I fully agree. I think we are saying the same thing with different words.

R. H. BEVIN: *How does Dr Morley handle the species of lucerne, subterranean clover, and phalaris, to ensure best use of climatic resources and to prevent strain on both pastures and livestock at various stocking rates?*

This is at present the subject of experiments with pure species, and various mixtures. I have no strong opinions, but it seems likely that mixtures could use resources more fully than do most pure stands.

P. B. LYNCH: *Successful management of a system of rotational grazing is greatly dependent on the skill of the manager. Would Dr Morley give more details of the rotational grazing technique used in his studies and could he comment on the difficulty of defining a rotation in terms of an experimental treatment?*

Perhaps it is true that the skill of a manager is more important than skill and knowledge in designing a grazing system. But I have no evidence that this is so; and presumably skill is the successful use of knowledge, and knowledge must be acquired by experiment and observation of definable treatments and phenomena. The rotational grazing technique used in the experiment described here was a 36-day grazing, 72-day spell, during winter, with a shorter cycle in autumn. All gates were open from mid-September until February. This is easy to define, but it is difficult to say whether the system was optimum. I am fairly sure it was not optimum, but it did appear to confer some advantages. Perhaps one could defer any comparisons until one knew which system was optimum; but by then experiments would be pointless.

G. B. CUMBERLAND (COMMENT): The effect of fencing on production in grazing trials could be of particular importance. There may be some effect on the quantities of meat and wool produced in trials such as Dr Morley's, due solely to animals being kept in small paddocks.

DR MORLEY: This is probably true, but perhaps not a major influence in the short-term. In the long-term, we must recognize that unduly high grazing pressure on small parts of a paddock could initiate a progressive degeneration over larger parts. Small paddocks may thus increase long-term stability.