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THE ECOLOGY OF PASTORAL PRODUCTION IN AUSTRALIA

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SUMMARY

As animal products are derived from plants, ecological studies are essential to the application of research findings and to the integration of research programmes.

The farmer aims at converting the physical resources of soil and climate into living material that can be exploited commercially, but the requirements of animals are relatively simple. The amount of forage grown on each property governs the number of animals that can be carried, but it is doubtful if present stocking rates exploit the full potential of the available forage.

Although numerous studies have been made of the toxicity of improved pastures, little is known of the respective merits of various pasture species for animal production. Further investigations are necessary to elucidate the relationships between the chemical composition of forage and the production of gametes, body growth and of wool.

Sheep populations tend to increase with the availability of forage, but in tropical Australia reproduction rates are low and a broad approach is needed in order to define the nature of the problems associated with ovine reproduction.

Comparatively slow progress is likely to accrue from the selection of breeding stock, although there is scope for selection for physiological traits likely to influence productivity.

The farmer can make only a few adjustments in property management in order to accommodate new practices suggested by research findings.

ANIMAL PRODUCTS are derived from plants, which produce forage when their requirements for nutrients, moisture, radiation and temperature are met. Ecology is the study of the interrelationships within such complex systems. The results of ecological studies are essential to the application of research findings to animal production, and also to the integration of research programmes designed to uncover new, but useful information. In the changing circumstances surrounding the animal industries, successful pastoral production depends largely upon the extent to which new information can be integrated with those activities that the pastoralist can control, so that he achieves efficient use of the resources available to him. This paper is backed by a strong conviction that the use of science by primary industry can yield handsome dividends. No apology is

offered for adopting an ecological approach, although some who regard themselves as "pure" scientists may be inclined to suggest that ecology is too "applied". Such an attitude cannot be condoned; no useful purpose is served by differentiating between, or attaching values to "pure" or "applied" research.

This paper aims at helping to orientate the thinking of both primary producers and of research workers towards common goals that they find mutually acceptable.

The farmer aims at controlling the conversion of the physical resources of soil and climate into living material that can be exploited commercially. Animal production introduces an additional, and rather inefficient biological step in this process.

Australia has the unhappy distinction of possessing the largest proportion of desert of any continent. Her human population is increasing and her national fortunes still depend largely upon the prosperity of the sheep industry. Thus, criteria important in judging the efficiency with which the abiotic resources are used include:

- (1) The productivity of the land used for sheep raising in relation to its productivity if it were used for other purposes.
- (2) The productivity of the industry in its present form, by comparison with the maximum of which it is capable.
- (3) The extent to which the natural resources of the country are developed and husbanded.
- (4) The stability of the industry with regard to its contribution to national income, the security it provides for those engaged in sheep raising, and the permanent employment it creates.

These concepts have both demographic and agricultural implications. As the human population increases, greater areas of arable land will be required for the production of human food and pastoral pursuits will be relegated to less favourable regions.

The Australian sheep industry occupies three major agro-climatic zones:

- (1) The high rainfall zone, which enjoys a mean annual rainfall of over 20 in., and which carries Merinos, and crossbred sheep for fat lamb production.
- (2) The wheat-sheep zone, in which sheep raising for both wool and lamb production is combined with wheat farming.

- (3) The semi-arid pastoral zone, where mean annual rainfall is below 20 in. a year and evapotranspiration is high. Here Merino sheep predominate.

The requirements of animals are relatively simple. They need a place to live and to reproduce, adequate food, water, protection from predators, and freedom from disease. However, man demands more of his flocks than mere survival; he needs a surplus of domestic animals to make the pastoral ecosystem produce meat and wool.

FOOD FOR SHEEP AT PASTURE

The amount of forage grown on each property is influenced by rainfall, evaporation, the temperature of the soil and of the air, the amount of solar radiation that is received, and the fertility of the soil. Only a part of this vegetation will be eaten by useful domestic animals; some will be consumed by useless indigenous or feral animals, or by pasture pests. One of several fates may befall the remainder: some may be harvested and stored for feeding back at a later date; some may be lost through weathering or burning; some may continue to grow and to reproduce. Of the forage that is eaten, some will be digested and the remainder voided, but, on being passed, it may contribute to the fertility of the soil, or to the transference of essential elements from place to place. Only a part of the digested food will be used for productive purposes; some will be needed for the maintenance of body function. It is usually stated that sheep require 3 lb dry matter/day to satisfy appetite. This would be contained in a cube of grass about 16 in. \times 16 in. \times 16 in. whose collection must be achieved through a small mouth (Willoughby, 1958). A pasture that provides 1,400 lb/acre — *i.e.*, 12½ cwt/acre — would have only ½ oz forage per square foot if all the plants were the same size and were evenly spaced. Thus sheep may be confronted with a considerable task in gathering their daily forage.

In the high rainfall and wheat-sheep zones, phosphorus is the most important plant nutrient applied as a fertilizer to increase forage production; in these zones over 28 million acres sown to subterranean clover are topdressed annually with superphosphate.

Small quantities of other elements (*e.g.*, zinc) are necessary to maintain swards of improved pastures in some parts of Australia, and other elements (*e.g.*, copper, cobalt and selenium) are essential to the health and productivity of grazing sheep.

The rhizobia associated with legumes enhance the nitrogen status of the soil, thereby providing a symbiotic association between legumes and grasses which improves forage production, and the use of legumes in ley farming has restored the fertility of extensive areas in the wheat-sheep zone that had been depleted by constant cropping (Cornish, 1949). Thus the establishment of improved pastures has contributed greatly to the husbanding of Australia's natural resources. However, pasture improvement is expensive, and at present there do not appear to be satisfactory answers to the question, "By how much can animal production be increased by the application of different amounts of fertilizer in specific regions?"

In the pastoral zone the nitrogen status of extensive regions is low and some areas are deficient in phosphorus. The use of fertilizers is uneconomic in such arid areas, and so far few exotic plants show promise of being able to improve forage production. Many of the plant communities in the pastoral zone have changed from their pristine state; in some, useful plants that can withstand stocking have become dominant; in others the useful plants have disappeared and extensive soil erosion has occurred (Condon, 1952; Ratcliffe, 1936).

In Australia pasture improvement is based on very few plant species, and agronomic criteria have been the main basis for their selection for different environments. In many instances the pattern of growth of the introduced species has resembled that of the indigenous, or the dominant native species, except that the introductions have obviously produced a greater abundance of forage in the spring. Less obvious, but of greater importance, has been the contribution to the production of forage in the winter. The present lack of a suitable technique for measuring low levels of forage production limits the assessments that can be made of the importance of this contribution.

Insufficient research has been directed towards the use of pasture, but it is already clear that purely agronomic measures are of little value for estimating potential livestock production, or for devising husbandry practices. Thus, at present, productivity of the pastoral ecosystem can be measured only in terms of reproduction rates, and the growth of body tissues and of wool.

In experiments at Canberra, A.C.T., the rate of gain in body weight of Merino wethers was less for each successive increase in pasture production. Rapid weight gains were achieved when the green pasture provided between 250 lb

and 1,500 lb dry matter per acre; thereafter practically no increase in the rate of weight gains occurred as the amounts of green forage or of dry pasture increased (Willoughby, 1959). Similarly field studies at Armidale, N.S.W., revealed a correlation between liveweight changes and the availability of green forage, and suggested comparable relationships between wool growth and green forage (Roe *et al.*, 1959).

Most of the species used for pasture improvement in Australia contain some toxic principles. The presence in important plant species of the pro-oestrogens which, upon assimilation, are converted into female sex hormones, create problems that are of special interest to pastoral production. The consumption of oestrogenic forage can enhance growth rates and milk production, but it can also lead to infertility of sheep (Moule *et al.*, 1963). Comparatively little is known of the biosynthesis of the pro-oestrogens but wide variations occur in the oestrogenic properties of different plants, both between and within seasons. Some of these differences can be attributed to such environmental factors as soil nutrients and moisture, light, and perhaps to changes in the leaf area index imposed by grazing. Fortunately, practicable methods are now available for measuring the oestrogenic properties of pastures as well as the isoflavone content of individual leaves.

The oestrogenic properties of subterranean clover did not become obvious until some fifty years after the initial interest in this species as a pasture plant. Similarly the toxic properties of *Phalaris tuberosa* were first described some forty years after this plant was introduced into Australia. Twenty years after this first description of toxicity (McDonald, 1942), it was realized that phalaris may produce two entirely different syndromes in grazing sheep.

Features of these situations of special interest in relation to the selection of pasture species include the long interval between the introduction of the plants and the manifestation of their toxic properties, the wide variations that occur in the toxicity of the same varieties growing in different locations, and the possibility of producing harmless varieties by the use of such mutagenic substances as ethyl methane sulphonate (Francis, pers. comm.).

A considerable amount of effort has been directed into studies of the toxicity of pasture plants; far less attention has been paid to the composition of pastures in relation to animal production. Studies at Canberra, A.C.T. (Arnold, 1960), provide the only known Australian example. In this

work comparisons were made between animal production from two subterranean clover pastures, one of which contained phalaris, and the other annual grasses. When judged by changes in liveweight and wool growth, the pasture containing phalaris was more productive than the one containing annual grasses. In December/January spectacular falls occurred in liveweight and in the rate of wool growth of the animals grazing both pastures. This occurred when the pasture "dried off" during the hot, dry summer at a time when there is usually adequate dry feed, which is considered to have a fair nutritive value.

For many years considerable emphasis has been placed on the protein content of pasture for both wool growth (Marston, 1955) and for semen production (Moule, 1963), but more recent investigations have indicated the need to re-examine these claims. Most of the protein reaching the abomasum of grazing sheep is likely to be of microbial origin (McDonald, 1962). Thus the digestibility of microbial protein will be important in considering the efficiency of conversion of dietary nitrogen. Variable changes in wool production have been noted following changes in the amount of protein consumed, but a substantial increase in wool production, which was due largely to increased fibre diameter, occurred within a week of casein supplementation into the abomasum. The nitrogen in casein infused into the abomasum was converted into wool more efficiently than other forms of dietary nitrogen consumed normally (Reis and Schinckel, 1961).

The ability of the sheep to digest protein in the abomasum and small intestine, and to absorb the end products of digestion seems to exceed the amount of nitrogen which can be used for protein synthesis. Therefore the efficiency with which nitrogen is used by sheep may be determined by the extent of protein degradation in the rumen and the loss of nitrogen absorbed from the rumen as ammonia. The response in wool growth to supplementation with protein is not adequate evidence that the response is due to protein *per se*, as protein may be used as a source of energy. In Merino sheep no significant association was found between wool growth rate and per cent. protein in rations ranging from 7.5% to 29% crude protein, and fed at 500 g/day, nor between rations containing 19% and 29% crude protein fed at 1,400 g/day (Ferguson, 1959). Large differences occurred between the levels of wool growth of the animal subject to different levels of intake (50 g v. 1,400 g).

Investigations into the effect of nutrition upon semen production revealed that there was a general trend for total sperm numbers, seminal vesicle weights and seminal fructose, which reflects testosterone output (Lindner and Mann, 1960), to increase with the energy content of the ration (Moule *et al.*, 1964). The response of the pituitary gland weights and of total gonadotrophin content was influenced largely by the protein content of the ration (Symington, pers. comm.). Field studies at Prospect, N.S.W., indicated that with rams at pasture some factor, which was probably the amount of green grass available, exerted a greater effect over semen production than did changing day length or ambient air temperature (Moule *et al.*, 1964).

SHEEP POPULATIONS IN AUSTRALIA

Increased sheep numbers consequent upon pasture improvement has been the most important factor contributing to the enhanced productivity of the Australian sheep industry, although mean fleece weight has increased by a little over 2 lb during the post-war years.

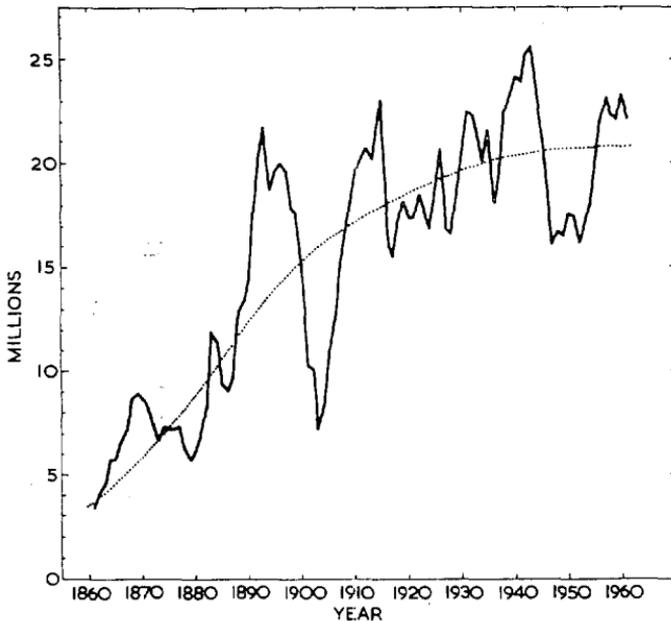


Fig. 1: The growth of the sheep population in Queensland. Note the rapid growth phase between 1860 and 1890, and the fluctuations around the plateau, which has existed for the greater part of this century.

In each of the Australian states, the growth form of the sheep population has followed a logistic curve typical of those for animals introduced into a new environment. In Queensland (Fig. 1) the sheep occupy a semi-arid environment where pasture improvement remains impracticable. Sheep numbers increased rapidly and fluctuated around the plateau of just over 20 millions, a figure first achieved some seventy years ago. By contrast, the growth form of the sheep population in South Australia (Fig. 2) shows two periods of rapid increase. The first occurred between 1840

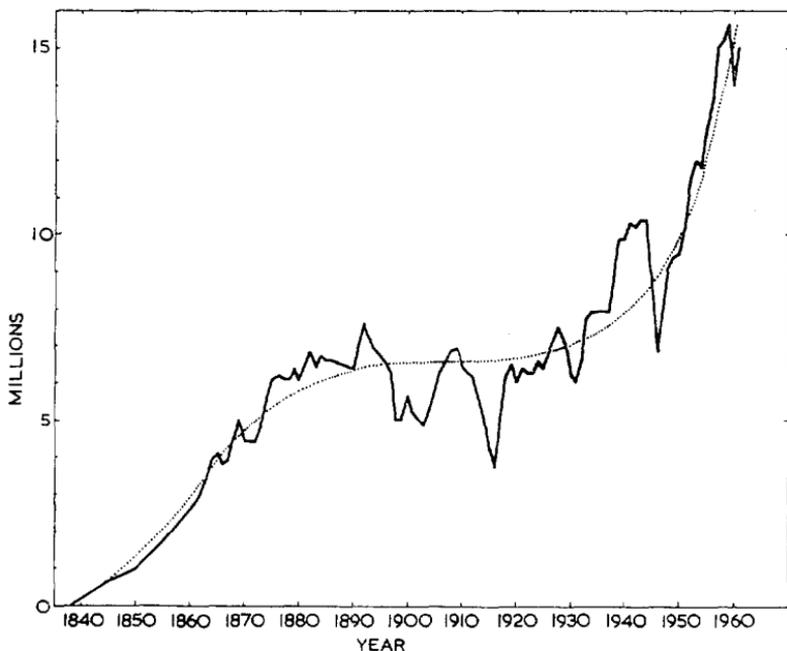


Fig. 2: The two phases of growth in the sheep population of South Australia. The marked increase in sheep numbers since 1930 has been due to pasture improvement.

and 1880 and the second commenced in 1940 when the increased forage derived from pasture improvement commenced to affect sheep numbers. It is hard to forecast when the curve for South Australia will reach its second plateau; it is also difficult to forecast the position in New Zealand where the growth form of the sheep population (Fig. 3) continues to be upwards. During the decade 1951-1960, New Zealand's sheep population experienced a mean annual growth rate of almost 4%; the maintenance of this rate of increase would mean a sheep population of almost

70 millions by 1970. In Australia the principal increases in sheep numbers have occurred in the high rainfall and wheat-sheep zones as the result of new land being brought into production and the fertility of older land being restored. The mean increase in stocking rate resulting from pasture improvement is estimated to be only 1.3 sheep/acre. The maintenance of current rates of increase in sheep

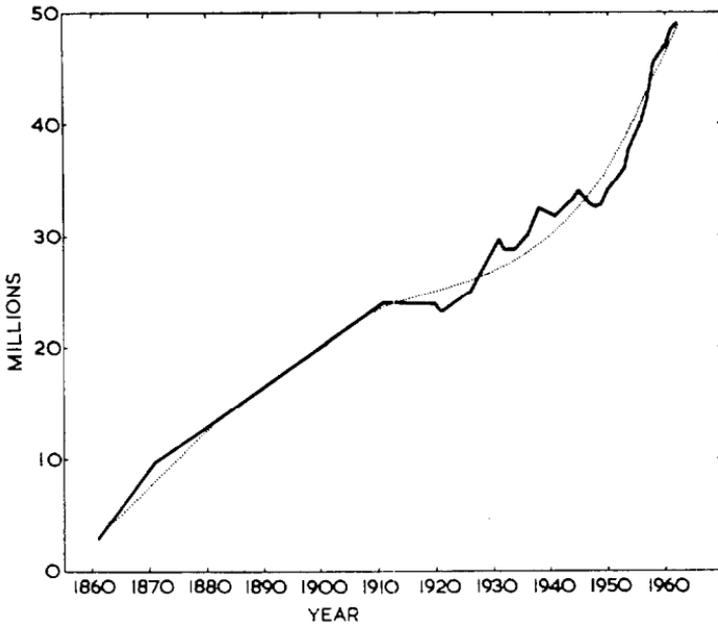


Fig. 3: The growth form of New Zealand's sheep population.

numbers in both Australia and New Zealand will depend upon the amount of additional land that can be brought into production, the rate at which the fertility of existing sheep country can be improved, the extent to which these advantages can be exploited through increased stocking rates, and, of course, the sequence of seasonal conditions determined by rainfall, etc.

Problems associated with attaining necessary increases in sheep numbers revolve around changes in the age composition of flocks and integrating the inherent reproductive rhythm of breeding flocks, which determines their nutritional requirements, with seasonal fluctuations in forage production, and avoiding other circumstances likely to have an adverse effect on reproduction. Reproduction rates of Australian flocks are low. Considerable attention has been paid to various facets of this problem; unfortunately,

TABLE 1: AGE-SPECIFIC DEATH-RATES (dx), SURVIVAL-RATES (sx), FEMALE FERTILITY-RATES (mx), LIFE TABLES (lx) DERIVED FROM DATA FOR 6,500 BREEDING EWES IN QUEENSLAND

<i>Pivotal Age (yr)</i> X	<i>Death-rate (dx)</i>	<i>Survival-rate (sx)</i>	<i>Life Table (lx)</i>	<i>Fertility-rate (mx)</i>	<i>lx.mx</i>	<i>lx.mx.X</i>
0.75	0.3863	0.6137	0.6137			
2.0	0.076	0.924	0.5671	0.310	0.1758	0.3516
3.0	0.029	0.971	0.5507	0.353	0.1944	0.5832
4.0	0.038	0.962	0.5298	0.358	0.1897	0.7588
5.0	0.127	0.873	0.4625	0.358	0.1656	0.8280
6.0	0.081	0.919	0.4250	0.272	4.1148	0.6888
7.0	0.094	0.906	0.3851	0.414	0.1594	1.1158
8.0	0.054	0.946	0.3643	0.351	0.1279	1.0232
				2.416	1.1276	5.3494

Gross reproduction rates (G.R.R.)=2.416

Net reproduction rate (N.R.R.) =1.1276

The capacity for increase (*r*) =0.0258

there seem to be few attempts to make complete investigations. The innate fecundity of Peppin Merino ewes is reasonably high (Dun, 1961; Moule, 1964) and data (Table 1) obtained in semi-arid Queensland serve to illustrate the need to use a broad approach in order to define the real nature of the problem under field conditions.

These age specific data allowed assessments to be made of the relative seriousness of mortality of the young, and of low female fertility.

Seasonal changes in reproductive function of the ewe influence both the fertility and the fecundity of the national flock, as the times chosen for mating sheep exert considerable influence upon reproductive performance. The final decision upon the timing of reproduction is influenced by such considerations as the probability of effective rains that will ensure sufficient forage will be available for the survival and growth of lambs, freedom from high ambient air temperatures, and the price of lamb on overseas markets. These compromises mean that the times chosen for mating sheep in Australia do not always favour high fecundity; in some instances they may depress fertility.

Because reproduction rates are low in Australia, ewes are frequently kept beyond the age when they should be cast. This leads to increased sheep numbers, but may also

increase mortality. The demands on the pregnant ewe are greatest when food is short, hard to locate and difficult to collect. Thus under-nutrition, and not starvation, may set the population's ceiling by increasing mortality among pregnant ewes and newborn lambs.

In a country where rainfall is unreliable and poorly distributed, and where wide seasonal fluctuations occur in forage production, woolgrowers are concerned primarily with the survival of their animals; thus stocking rates tend to be limited by the periods of lowest forage production. Stocking rates that give maximum pasture use, and hence highest production per acre, usually exceed those that will yield maximum production per head, and the safe long-term carrying capacity of the property (Drake and Elliott, 1960; Tribe and Lloyd, 1962). Thus the probable increase in risk of economic loss resulting from increased stocking rates must be assessed before full advantage may be taken of pasture improvement. These risks will be manifest as:

- (1) Reductions in reproduction rates, and in the growth of body tissues and wool.
- (2) Increases in the effects of seasonal drought, and the need for supplementary feeding.

The mitigation of drought remains a challenging task to all Australians. In the semi-arid pastoral zone, techniques that allow flocks to escape from the effects of drought are likely to be preferred; in the wheat-sheep and the high-rainfall zones, fodder conservation is possible, though not popular. In the light of present knowledge, this conserved fodder is likely to be valuable when it is necessary to feed for survival; at present there is no satisfying evidence that supplementary feeding with conserved fodder will enhance production.

The risk of increased parasitism and disease constitute another type of problem that may arise out of increased stocking rates. Worm infestations of sheep vary widely according to type of husbandry and to geographic and climatic conditions. In natural populations, parasitism is a "density dependent" factor, and the risks of reinfestation of grazing sheep may also increase with increased stocking rates (Gordon, 1958). Parasites do not enjoy a normal distribution throughout the host population (Li and Hsü, 1951); genetic factors may well influence the reaction of individual animals to infestation (Whitlock and Madsen, 1958). Worm parasites harm sheep by decreasing appetite and the apparent digestibility of food, by removing blood,

by reducing body and wool growth rates, and in some instances by causing mortality. Frequently sheep whose productivity is reduced show no obvious signs of being affected.

Some infectious diseases may also be "density-dependent"—*e.g.*, conditions affecting the feet of sheep for which the moisture, so essential to high stocking rates, is also a predisposing factor.

THE SELECTION OF STOCK

The selection of stock provides the farmer with opportunities to vary, or to enhance the level of animal production obtained from the available resources. The choice between species and breeds is more likely to be dictated by economic and even physiological considerations; up to the present, selection for physiological traits has not occupied a very important place in the thinking of many people.

The theory of selection is comparatively simple. For the purposes of this discussion it was summarized (Rae, 1962) by the following formula to express the annual rate of genetic gain achieved by selection:

$$\text{Genetic gain/year} = \frac{\text{Heritability} \times \text{Selection differential}}{\text{Generation interval}}$$

Therefore the rate of genetic gain can be improved by increasing either the accuracy of, or the amount of selection, or by decreasing the generation length, or by combining any two or three methods.

The main applications of these concepts to sheep breeding have been:

- (1) The calculation of the heritabilities of various traits.
- (2) The use of measurements as an aid to phenotypic selection for the traits that have high heritabilities, and that are of economic importance.
- (3) Increasing the accuracy of selection for genotype by the use of progeny or family tests.
- (4) Determining and using genetic correlations.

These procedures are based on the relatively simple concept that individual productive characters are controlled by many genes, each with small additive effects. They disregard many extremely complex possibilities that cannot be elucidated until a large amount of difficult, long-term, expensive research has been undertaken. The advisability of embarking on such a programme must be judged on the probable input-output relationships with regards to the effort needed by research to discover, and by woolgrowers

to apply new findings, and to the probable dividends to be derived from their doing so. Increases in productivity through mass selection programmes are likely to be comparatively slow, even when considerable selection pressure can be exerted in favour of desirable traits whose heritability is high. However, low reproduction rates limit selection pressure. Genetic gains are usually permanent, and as the selection of breeding stock is popular two questions present themselves:

- (1) How much progress is effected by present methods of selection?
- (2) Are there any other approaches to increasing animal production which are likely to be more fruitful more quickly?

The selection of high producing Merinos can be aided by the use of fleece measurement (Turner, 1956) and there is ample evidence that the general principles of animal breeding can be fully applied in the breeding of stud sheep in the Australian Merino industry. However, considerable difficulties have to be overcome in devising extension programmes that will ensure that these methods be adopted by stud breeders.

It is not desired to give the impression that the tasks facing research into animal breeding are complete, and that extension is all that is needed. So far the emphasis has been placed only on selection for traits which represent an end product; little attention has been paid to the selection of animals for physiological characters. For the purposes of discussion, selection for fecundity constitutes a useful example. Fecundity refers to the power of a species to increase in numbers. This in turn demands selection for early attainment of puberty, frequent breeding with high rates of gamete production and of fertility, a long breeding life, and low mortality. There is now evidence that the twinning rate of Merino ewes may be increased by selection (Turner *et al.*, 1962), and there is also the possibility that the selection of rams for high scrotal sweat production may be advantageous in selection for hot environments (Moule and Waites, 1963).

Many experiments designed to investigate reproduction in sheep have been unsatisfactory as they have examined only one facet of the problem. Most workers would agree that there is an urgent need to record appropriate vital statistics so that accurate assessments can be made of the investigation programmes that are required. Present indications are that work is needed on ways of increasing

female fecundity, and of improving survival rates among the newborn. While the contribution of disease to reproductive failure should never be overlooked, it would seem that studies of the physiology of reproduction are most likely to lead to increases in both fertility and fecundity. For example, investigations into the effect of nutrition upon semen production revealed marked differences between Peppin and South Australian Merinos in their response to rations containing various levels of protein and energy (Moule *et al.*, 1964).

Differences also occur in the nutritional efficiency of wool growth according to breed (Daly and Carter, 1955; Ferguson *et al.*, 1949), strain (Dunlop *et al.*, 1960), and individual sheep (Schinckel, 1963), and their levels of food intake (Ferguson, 1959; Ferguson *et al.*, 1949), the mechanisms underlying these differences are not understood. The excretion of nitrogen in the faeces is similar for all sheep at comparable levels of N-intake on the same type of diet. This would imply that differences between the digestive efficiency of sheep may not be an important factor in converting dietary nitrogen into body protein.

Information is needed on the suitability of different breeds, and of fleece types for specific environments (Hayman, 1953, 1955), and the effects of environmental conditions on the efficiency of wool production.

THE PRODUCTIVITY OF SHEEP AT PASTURE

Reproduction, the growth of body tissues, and of wool are the productive phases of the Australian sheep industry.

A large part of the pastoralist's income is derived from wool, but wool growth receives little direct attention in husbandry practices. In its present form, sheep husbandry aims primarily at ensuring survival, preventing serious loss of body weight and, where possible, at fostering rapid body growth.

An understanding of the physiological basis of wool growth is a prerequisite to attempts to improve wool production through better nutrition. Follicle development commences prenatally (Short, 1955b); the total number of follicles is influenced by genotype (Merino *v.* Longwool), and by size of the newborn (Schinckel, 1955a; Short 1955a). Maternal nutrition influences foetal size and hence total follicle numbers, but only severe undernutrition can decrease the number of secondary follicles per primary follicle (Schinckel, 1953, 1955b).

Both birth weight and the proportion of follicles actually growing fibres at birth are strongly correlated with maternal nutrition. Most secondary follicles mature after birth, so unfavourable pre-natal conditions mean that a larger proportion of wool follicles complete their development in the post-natal period. Thus, post-natal nutrition determines the extent to which post-natal growth and follicle development can compensate for pre-natal restrictions. Preferential treatment of stock so as to ensure adequate nutrition to achieve optimum reproduction rates and birth weights, and the rapid early post-natal growth of lambs, will provide for the development of the full genetic potential for the follicle population. Although considerable attention has been given to weaner ill-thrift, the present indications are that post-weaning limitations on growth rate have no permanent effect on wool growth, unless they are severe and prolonged (Donald and Allden, 1959).

Marked seasonal fluctuations occur in the rate of wool growth, and in grazing sheep these can be related mainly to the availability of green forage, though the reproductive status of the ewe, lactation, and the composition of the pasture (Williams and Schinckel, 1962) also exert their respective influences. There is also evidence from pen experiments that climatic elements may exert an effect on wool growth rate, but on present evidence it seems that nutritional changes dominate the picture.

Body growth influences the amount of meat derived from a carcass, and the age at which animals are capable of reproducing. Growth is an extremely complex process, which is not easy to define. Facets of this problem relevant to animal production include the finding of adequate criteria for measuring growth, and the influence of breed, age and nutrition on the rate of increase in body mass, and on conformation. In mutton production the rate of growth is of far greater interest than final weight; growth rate governs profitability because it determines the time for which sheep have to be fed, and it influences carcass composition and hence price.

Considerable information is available on the effect of the selection of breeding stock, and of nutrition upon conformation, growth rates, and the differential development of the carcass. However, clear definitions are needed for both the nutritional requirements for growth of young sheep at pasture and of the ability of various pasture

species to meet these requirements. Thus pasture utilization emerges as the subject most urgently in need of research in relation to all phases of sheep and wool production. The critical levels of pasture production, below which grazing sheep experience increasing difficulty in obtaining their nutritional requirements, are in need of further investigation. This information would be especially pertinent to the intensive use of improved pastures in high rainfall zones; it is also relevant to the arid zone where animals may have to expend considerable time in walking and in grazing in order to gather sufficient food (Moule, 1956). These considerations raise further questions about the effects of pasture intake and its utilization by grazing sheep. Precise answers cannot be given to questions about the optimum system of grazing management to use. A number of experiments which have compared rotational and continuous grazing at similar stocking rates have not shown significant differences in animal production between the two systems (Wheeler, 1962). There would appear to be merit in controlling the grazing of ewes during early pregnancy, if this practice is necessary to ensure adequate pasture will be available for breeding ewes during late pregnancy and lactation. The advantages to be derived from adequate nutrition for such animals and for growing lambs, are well documented; how to achieve the required nutritional regimens at least under Australian pastoral conditions is not so clearly understood.

Sheep at pasture pursue their own diel activities — *i.e.*, their timetable of grazing, ruminating, and resting. In doing so, they make compromises between innate desires to satisfy hunger, thirst, the urge to reproduce, and such components of the environment as air temperature, the availability of pasture, the distribution of water, and competition for the available forage.

The importance of these subjects is now being recognized in Australia. Studies at Canberra, A.C.T., showed that, when confined on either lucerne or *Phalaris tuberosa*, sheep tended to select the leaves rather than the stems of the plants. Thus they chose material with the highest nitrogen content. The selectivity of grazing was directly related to the amount of forage available. When stocking rates were high, the animals were forced to consume forage of a lower nitrogen content than the material they had the day before. As the amount of pasture available to the sheep decreased, grazing time increased, but the time spent chewing the cud decreased (Arnold, 1960).

There are very few estimates of the energy expended in grazing, which would include the effects of such things as walking, harvesting grass, climatic and metabolic factors. The only Australian observations showed an increase of from 10% to 30% in the maintenance requirements of heavy sheep grazing good pasture but the increase amounted to between 50% and 100% for sheep of medium and low weights, and which maintained their liveweights while grazing progressively poorer pastures (Lambourne, 1961).

AN ECOLOGICAL APPROACH TO ANIMAL PRODUCTION

The environment influences where and how animals live. Domestic animals are confined to set areas of land and are often unable to avoid or escape from environments that are unfavourable to them. Individual components of the environment influence animal production, but the animal reacts as a whole to its environment as a whole. Thus the reaction of the animal to its environment provides the key to a reasoned approach to animal husbandry.

Man's control over domestic animals introduces human judgement as a major factor in the pastoral ecosystem. Successful animal production demands considerable capacity to attend to detail, but there are only a few basic adjustments that the pastoralist can make to influence the productivity of his property. In Australia, aridity is an important factor governing the extent to which pastoralists use the various adjustments available to them. The main adjustments that can be made include:

- (1) The application of plant nutrients, including water, so as to influence forage production.
- (2) The selection of species for pasture and forage crops.
- (3) The provision of fences and watering facilities that will permit control over livestock.
- (4) The placing of stock within subdivisions, so as to ensure better nutrition for different classes of stock — *e.g.*, breeding ewes and growing lambs.
- (5) The conservation of forage to feed back to the animals in an effort to maintain, or to increase numbers.
- (6) The timing of reproduction by controlling mating.
- (7) Adjustments to animal numbers and to the age and sex structure of flocks.
- (8) The selection of animals suited to different kinds of production and different environments.

- (9) The timing of shearing.
- (10) The control of parasitism and disease.
- (11) The general amelioration of the environment by the provision of shelterbelts, the eradication of predators and of competitors for the available food.

The application of knowledge derived from current and future research must be fitted within this quite small number of farm operations. Similarly, research initiated to aid industry must keep in mind the farm operations through which it may be applied. The orientation of biological research towards agriculture does not detract from its scientific merit, though it adds greatly to its difficulty. The scientist is anxious to discover the mechanisms that are essential to the function of productive systems but few attempts have been made to study the ecology of pastoral production. Work that could be undertaken during the next twenty years may yield data from which estimates can be made of the distribution of energy within such productive systems. In the meantime, we must be content with descriptive accounts, as there are extremely few measurements of input-output relationships which will serve to guide woolgrowers in the application of research findings to animal production. Those concerned with research into animal production have a vast array of mechanisms to investigate. Their scientific judgement will be reflected by the importance, within its ecological setting, of the work they choose to do. The pastoralist who endeavours to apply the results of research will find the need to integrate his thinking about the strategy and tactics of management that ensure the welfare, efficient raising and optimum productivity of his domestic animals, consistent with the maintenance, or improvement of their respective ecosystems.

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DISCUSSION

DR D. G. EDGAR: *I find it surprising that adjustment in the time of mating ewes gave benefits lasting over 7 to 8 months. Would Dr Moule comment?*

DR G. R. MOULE: Later mating ensured (i) greater fecundity and (ii) faster growth rates of the lambs. These advantages resulted in the marketing, off their mothers, of larger numbers of lambs.

DR EDGAR: *Was the increase in ovulation rate due to improved nutrition or advance of the breeding season?*

DR MOULE: Although the matter was not investigated, there is every reason to believe that the increase in ovulation rate was due to the advance of the breeding season.

C. L. SANDBROOK: *The N.Z. Institute of Agricultural Science has estimated that, using known techniques, there is a potential for increased carrying capacity of 81% nationally. Could Dr Moule give a similar estimate of Australian potential?*

DR MOULE: Less than half and only a little more than one-third of the areas suitable for pasture improvement in the high rainfall and the wheat-sheep zones, respectively, are actually sown to improved pasture, and there are still extensive areas in Queensland to be brought into production.

Q: *Could Dr Moule please tell us about the ecology of sheep in relation to fleece count?*

DR MOULE: Average spinner's to best top making and average to good top making wools predominate in the pastoral zone. Average spinner's wools with some fault are produced in the wheat-sheep zone and good spinner's wools are obtained from much of the high rainfall zone. The scoured specialities are produced in tropical Australia.

PROFESSOR W. V. CANDLER: *By the "ecological approach" does Dr Moule imply the same as Dr McMeekan when he says that, "sometimes we should abuse the animal and sometimes the pasture", or is there something more? Is the "ecological approach" essentially the same as the "whole farm approach" or what the engineers call "systems analysis"? Does Dr Moule think that the ecological approach can help in the allocation of research funds?*

DR MOULE: An ecological approach is essentially a whole farm approach. It can be helpful in allocating research funds because it demands a consideration of the relevance of the proposed work, of input-output relations, of the use of available resources including capital, and of interactions between various components of the ecosystem.

E. D. ANDREWS: *What is the current thinking regarding the emergence of diseases such as phalaris staggers and oestrogenic infertility many years after the introduction of the pasture plants responsible? Could there perhaps have been a degree of unaware-*

ness of the disease or is it likely that lag in emergence could be associated with changing management practices?

DR MOULE: There may have been a degree of unawareness but changing management practices, including the selection of pasture species and changing soil conditions, may all have contributed.

DR J. W. MCLEAN: *Dr Moule has indicated the close relationship between the various types of Merino and the climatic conditions under which they are run in Australia. I would like to ask how much this is due to a true ecological relationship and how much to other factors such as tradition and availability of breeding stock.*

DR MOULE: There have been too few studies to know. Predisposition to body strike may have tended to decrease the popularity of strong wool merinos in the Tableland districts of N.S.W. On the other hand, the S.A. strong wool Merino may be quite highly productive in the pastoral zone of N.S.W. which is the traditional home of the Peppin Merino.