REFERENCES

BOOYSEN, P. DE V., TAINTON, N. M., and SCOTT, J. D., 1963. Shoot apex development in grasses and its importance in grassland management. *Herb. Abst.* 33: 209–13.

BRANSON, F. A., 1953. Two new factors affecting resistance of grasses to grazing. *J. Range Mgmt.* 6: 165–71.

BROUGHAM, R. W., 1959. The effects of frequency and intensity of grazing on the productivity of a pasture of short-rotation ryegrass and red and white clover. *N.Z. J. Agric. Res.* 2: 1232–48.

BROUGHAM, R. W., 1960. The effects of frequent hard grazings at different times of the year on the productivity and species yield of a grass-clover pasture. *ibid* 3: 125–36.

BROUGHAM, R. W., GLENDAY, A. C., and FEJER, S. O., 1960. The effects of frequency and intensity of grazing on the genotypic structure of a ryegrass population. *ibid.* 3: 442–53.

CORKILL, L., 1956. The basis of synthetic strains of cross-pollinated grasses. *Proc. 7th Int. Grassl. Cong.* 427–36.

DOAK, B. W., 1954. The presence of root-inhibiting substances in cow urine and the cause of urine burn. *J. Agric. Sci.* 44: 132–39.

EDMOND, D. B., 1958a. The influence of treading on pasture. A preliminary study. *N.Z. J. Agric. Res.* 1: 319–28.

EDMOND, D. B., 1958b. Some aspects of soil physical condition on ryegrass growth. *ibid.* 1: 652–9.

EDMOND, D. B., 1962. Effects of treading pasture in summer under different soil moisture levels. *ibid.* 5: 389–95.

EDMOND, D. B., 1963. Effects of treading perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) pastures in winter and summer at two moisture levels. *ibid.* 6: 265–76.

EDMOND, D. B., 1964. Some effects of sheep treading on the growth of 10 pasture species. *ibid.* 7: 1–16.

GOODALL, V. C., 1951. The day and night grazing system. *Proc. 13th Conf. N.Z. Grassl. Assoc.* 86–96.

HUNT, L. A., and BROUGHAM, R. W., 1966. Some aspects of growth in an undefoliated stand of Italian ryegrass (*Lolium multiflorum* LAM.). *J. App. Ecol.* (in press).

JANTII, A., and KRAMER, P. J., 1956. Regrowth of pastures in relation to soil moisture and defoliation. *Proc. 7th Int. Grassl. Congr.* 33–44.

LANCASHIRE, J. A., 1961. *A study of the reaction of four grass species (perennial ryegrass, timothy, cocksfoot and browntop) to an artificial treading treatment.* Massey Agric. Coll. (N.Z.) thesis.

SEARS, P. D., 1953. Pasture growth and soil fertility. Part VII. *N.Z. J. Sci. & Tech.* 35A: 221–55.

WALKER, T. W., 1956. The nitrogen cycle in grassland soils. *J. Sci. Fd. Agric.* 7: 66–72.

SOME PEDOLOGICAL FACTORS OF IMPORTANCE TO THE PASTURE ECOSYSTEM IN THE SOUTH ISLAND

E. J. B. CUTLER

Soil Bureau, D.S.I.R., Dunedin

It should not be necessary to emphasise to ecologists the importance of the soil in the pasture ecosystem. Yet it is true that ecologists are not always aware of the limitations of soils with respect to the ecosystem. This is in part because soils are not as easily observed as plants or animals, and in part because of the lack of a course in pedology in the training of ecologists.

If we were able to construct or breed pasture soils, what would be the specifications we would ask for? They are many and would include: Mineral assemblages supplying readily available plant nutrients, non-fixing clays, medium texture, adequate root space, free drainage, fine but stable granular structure, medium density, high structural stability, high bearing capacity under wet conditions, and high moisture storage. Soils of the natural tall grasslands of Asia and North America, the prairie and chernozems, are the closest naturally occurring soils to this ideal, but very few soils of the South Island even approach it. Our soils with good physical properties usually have nutrient problems and vice versa. Most of our soils depart in more than one respect from the ideal specification; for example, most have only weakly (some moderately) developed structure, and are easily compacted when dry and puddled when wet. Several contributions to this symposium cover the problems of soil chemistry, and this paper will therefore be restricted to some of the more important physical properties of soils as they affect the pasture ecosystem.

SOIL FACTORS LIMITING MOISTURE STORAGE AND AVAILABILITY

Many soils have low available water storage. The first class of these are the shallow and stony soils (associated with yellow-grey earths and brown-grey earths) widespread on the plains of Canterbury and Otago. Many hold less than 2 inches of available water in the root zone. They dry out rapidly in summer, especially where cover is open and they are closely grazed. The top few inches dry out first and growth falls off because of drought and the low concentration of nutrients below the top few inches, especially in soils with low biological activity and slow soil mixing. Efficient irrigation of such soils is difficult because under conventional methods (border dyke system) at least 4 inches of water are applied at a time, and there is a loss through drainage of half the applied water and more, if the soil is nearer field capacity. One irrigator in Otago supplies up to 80 inches of irrigation water per annum with a probable wastage of at least 50 inches. On the other hand these shallow and stony soils are less likely to pug under heavy stocking than deep silty soils because of their free drainage and low clay content. Because their water storage capacity is low they need frequent irrigation with small quantities of water. This can be done only by spray irrigation, a method which has not been encouraged yet deserves more study.

The second class includes all the drier yellow-grey earths and deeper brown-grey earths, mostly formed on loess. An examination of the measured available water storage figures suggests that these soils have more than adequate available water storage capacity but soil moisture measurements must be interpreted in relation to the structure of the horizons and variation in seasonal rainfall. Although rainfall may be slightly higher in summer than winter, the effectiveness of summer rain is relatively low because of high evapotranspiration. Consequently these soils have a water deficit in summer, and it may be severe if preceding seasons have also been dry. It is evident that water availability is severely restricted below about 10-12 inches because of dense blocky or coarse nutty structure, and low below 15-18 inches because of the very dense hard massive columnar structure. Root distribution in these horizons is restricted to cracks between aggregates which in many yellow-grey earths are eight to ten inches apart. The rate of water movement into the aggregates is slow because the outer crust consists of a hard iron-encrusted layer. Water, therefore, bypasses the aggregates and moves down cracks below the root zone. Available moisture is therefore less than measurements of water storage capacity and rainfall suggest. Prairie soils, on the other hand, are a much more favourable physical environment for plants. Subsoils are less dense, more friable, and structural aggregates are small. Consequently, roots penetrate deeply and ramify widely, moisture moves down the profile more evenly and penetrates the aggregates, the interiors of which are never more than a few millimetres from plant roots. For a given quantity of water the prairie soil will not only retain more in the root zone, but this stored water is more easily available.

The third class includes wetter yellow-grey earths and soils of the yellow-grey to yellow-brown earth intergrade. The structure profile of these is similar in many respects to the yellow-grey earths except that they are more frequently gleyed because rainfall is higher and the pan impedes drainage. In extreme cases gleying is strong and root range restricted in depth, so that in dry periods growth is likely to be more retarded than in a free draining soil with deeper rooting. In addition the soils readily waterlog in wet seasons if not drained.

THE EFFECT OF COVER ON MOISTURE PROPERTIES OF SOILS

Most of the soils described above carried in their natural state dense tussock which protected the soil from direct evaporation and probably acted as a collecting cover for dew and fog drip. On steep slopes natural cover also helped to reduce the rate of surface runoff and flood peaks. Closely grazed pasture, on the other hand, is a poor insulator of the soil surface. In dry weather there is consequently a greater loss of moisture from the soil under pasture than under dense tussock, and the loss may even be greater where the topsoil structure is broken down and the surface compacted. In this case infiltration is reduced and evaporation increased. The difference in soil moisture between closely grazed pasture and nearby native grassland or tall ungrazed crops like lucerne is so marked as to be easily recognised in the field and has been observed by many people. In order to make the most efficient use of available water on soils with limited water storage new types of pasture and new techniques of management may be necessary.

THE CONSERVATION DILEMMA

A related problem is that of controlling runoff and the conserving of soil moisture. There are large areas of both hilly and steep lands in the South Island which could possibly be converted from tussock or scrub to exotic pasture. The demand for increased production is already making people look at the potential of these lands. As the soils are converted to carrying pasture they will become more compact, loose turf layers will disappear, and the natural water conserving cover will be reduced. The result will be to lessen infiltration, increase runoff, probably increase erosion on lower slopes, and cause severe flood problem on lowlands, as has occurred on the pumice lands of the Central North Island. Water conservation problems are serious enough on downlands but they will be much more serious on hilly and steep lands. Conservators of soil are dismayed with the prospect because in the south winters are longer and the soil surface will have only a sparse cover (under exotic pasture) during winter, and in dry summers the soil surface may be bared to a certain extent, so that the likelihood of serious runoff and erosion is relatively greater than in the north. The pasture ecologist may be able to reduce the risks by choosing suitable pasture species, preferably tussocky types and by pasture management, but this may not be enough. Possibly multiple land use—both exotic forestry and improved grassland, with the relative proportions of each decided on the basis of soil and catchment characteristics—may be the safest way to use these steep and hilly lands. This would be contrary to the traditional New Zealand approach to farming which visualises pasture from coast to mountain top — an ecological 'peneplain'—whereas what is needed is an ecological mosaic.

SOILS WITH ADEQUATE MOISTURE

Let us now look at the soils (mostly yellow-brown earths) with adequate moisture, usually soils also with relatively deep friable granular, nut or crumb structure. Broadly we can classify these in three groups. Firstly, there are the weakly weathered upland and high country yellow-brown earths with relatively low bulk density, weak crumb structure and low nutrient status. These soils are relatively high in vermiculite and amorphous oxide clays, both undesirable features as far as the nutrient cycle is concerned. Such soils are a "sink" for phosphate and may also require potash under intensive use. Large areas of these soils are eroded and should be reserved for soil and water conservation. Where climate and topography are more favourable to the establishment of a stable pasture ecosystem, conversion to exotic pasture may be desirable. Secondly, there are the southern yellow-brown earths (moderately weathered) with more stable structure and small content of amorphous clays. These are well represented in Southland and are among the most favourable soils in the pasture ecosystem because of their good physical properties and the ease with which their nutrient status can be improved. Thirdly, there are small areas in Nelson of moderately to strongly weathered yellow-brown earths with kaolinitic clays and with relatively low nutrient status and low reserves of nutrients. These are problem soils for both pasture ecologists and foresters because of their low nutrient status, and to a lesser extent their poor structure.

MODIFICATION OF SOIL PROPERTIES

Several questions arise concerning the possibility of modifying soils to make them better suited to the pasture ecosystem. Man has made some changes, largely in the nutrient level of the topsoil; and the change from native vegetation to exotic grasses, plus the influence of grazing animals have modified the organic cycle and to a lesser extent soil structure. Coarse nutty-structured soils originally under forest become granular to fine nut-structured—a favourable change; but the change in yellow-grey earths from a crumb structure under tussock towards a nut structure under exotic grasses is less favourable. These changes were not intentional. Where changes in soil structure are desirable can we induce them more rapidly? Is it wise to put fertilisers only on top of the soil profile or should they be placed deeper to encourage deeper rooting—a very desirable effect in soils which dry out? Should we attempt to modify physical properties of soils by mechanical methods such as deep ploughing or subsoiling? Various techniques of subsoiling are in vogue on yellow-grey earths, and although these techniques may receive government subsidy little is known about their effect on the soil or even if they are worthwhile. On wet yellow-grey earths they may even be detrimental to at least structure and drainage. Obviously this is a problem which can be solved only when we know more about the formation of such soils and the processes now operating in them. Is the abandonment of liming of many soils a wise change? Lime has other desirable effects apart from changing soil reaction.

Attempts at soil amelioration (as for example, subsoiling), can hardly be said to be soundly based. They are often applied to our soils on the basis of overseas experience most likely gained on quite different soils. Is there any way that we can approach the problem more rationally? I suggest there is: Let us first construct a modal soil from the point of view of the pasture ecosystem and then see how we might modify our present soils to approach this ideal.

The prairie soils may be considered the ideal for the brown-grey and yellow-grey earth zone, and the brown forest soil for the yellow-brown earth zone. If we could modify soil processes so that they were directed towards these ideals we would also modify the whole ecosystem. For example, increasing the base status of subsoils as well as topsoils would create conditions more favourable to soil flora and fauna which in turn would improve structure, aeration, water storage capacity and drainage, as well as increase the depth of soil available for grass roots. It would be necessary for ecologists to take an active part in any study of soil amelioration because the kinds of plants growing on the soil and the way they are utilised will influence the changes taking place. The piecemeal study of parts of the pasture ecosystem such as plant breeding and soil chemistry have their place, but there is also need for a broader approach—a pedological-ecological one which would integrate these individual studies into the whole system.

THE EFFECT OF EARTHWORMS ON PASTURES

S. M. J. STOCKDILL

Department of Agriculture, Palmerston, Otago

INTRODUCTION

Without earthworms pasture production may be limited to slightly more than half the true potential. With beneficial earthworms increased production is associated with pronounced physical changes that are readily observed in the field. Changes in both physical and chemical properties are revealed by analyses of soils from pastures with and without beneficial earthworms. Some of these changes are direct results of earthworm activity, others may be brought about indirectly.

BENEFICIAL SPECIES

Lee (1959) has recognised 192 species in New Zealand. The great majority are natives found mainly under native vegetation. Some are, however, found under sown pastures. Populations as high as 20 per square foot have been recorded in the absence of introduced species with no obvious beneficial effects.

Of the 14 introduced species of the family Lumbricidae *Allolobophora caliginosa* is the one we are most concerned with in pasture improvement, and references to beneficial earthworms will be confined to this species, unless otherwise stated. *Eisenia rosea* and *A. chlorotica* also appear to be beneficial but are of lesser importance. *Lumbricus rubellus* is widely distributed and is often found in areas not populated with *A. caliginosa*, without beneficial effects being noticeable. Species that are not beneficial are, however, of importance in one sense: one or other of them occur in most places, thus misleading farmers and others into believing that introduction of beneficial species is not required.

AREAS NOT POPULATED

The distribution of beneficial species has been studied by Nielson (1951a, 1962a) who has found *A. caliginosa* to be absent from many soils because calcium levels are too low (4 milli-equivalents % or less). On the other hand, some soils with adequate calcium levels have remained unpopulated simply because beneficial species have not been introduced, either intentionally or by accident. In some localities inadequate soil moisture has limited both the extent and density of populations.

Although no estimate of the area remaining unpopulated by beneficial species may be made, it includes most of the upland and high country yellow-brown earths of the South Island, and probably other strongly leached soils in which calcium levels have not been raised by liming. Extensive areas of these soils have been developed into improved pastures but, although limed to a level adequate for *A. caliginosa*,