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THE STUDY OF ECOSYSTEMS

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The term "ecosystem" may be defined as

> "an open system comprising plants, animals, organic residues, atmospheric gases, water and minerals which are involved together in the flow of energy and the circulation of matter".

It is an all-embracing system and this gives it its greatest value—that it is treated as a whole, not as a number of separate parts.

As papers on soils, papers on climate and others on plants and animals, even if they penetrate some way into neighbouring fields, do not add up to a symposium on ecosystems I thought I would resist the inclination to discuss soils and nutrient cycling, and instead deal more generally with the study of ecosystems. This might provide a wider perspective and encourage discussion to range more freely.

SOILS AND ECOSYSTEMS

There is no great difficulty for a soil chemist to talk about ecosystems. The father of soil science, Dokuchaev, sixty-five years ago wrote of the need for a new science ("an independent and honourable one") to study the complex correlations and interactions of surface rocks, the earth's sculpture, soils, waters, climate, vegetation, animals and men (Rode 1962). He thought it would come soon and that pedology would be the nucleus of it. He was wrong on both counts, as it took many years to emerge, and from its essence no one aspect of it can be considered nuclear, but come it certainly has.

Dokuchaev well understood the interrelationships of soil and its environment but it was not until 1941 that Jenny defined the factors of soil formation clearly in the equation

$$\text{soil} = f(\text{cl, o, r, p, t} \ldots .)$$

where cl = climate, o = organisms, r = relief, p = parent material and t = time. Without straining definitions this could as easily be ecosystem = f(cl, o, r, p, t . . .) (Krajina 1961) In other words the forces moulding the soil are the forces moulding the ecosystem as a whole.

This is confirmed by our experience. Where soil is studied in relation to some factor of the environment the whole ecosystem needs to be taken into account. There seems little point in studying the ability of soils to supply plant nutrients and ignoring animals dying of hypomagnesaemia, or of studying fine details of nutrient cycles in beech forests and ignoring the effects of moisture or the slow rates of tree growth.

It is, then, a reasonable transition from thinking in terms of soils to thinking in terms of ecosystems. The next stage also follows:

In soils one is familiar with the idea of defining soils in terms of processes, and indeed, soils are often more significantly expressed in these terms than in terms of the soil itself. There are many examples of this in New Zealand soil classifications and Jenny (1961) has written:

> "Dynamics and energy flow per unit area of land . . . will become as fundamental in conceptual importance to soil science as are free energy and entropy in chemistry."

It is the same with ecosystems. As Ovington (1962) has suggested, processes seem likely to give more significant expression to the ecosystem than any particular part of it, such as trees.

ECOSYSTEM PROCESSES

There are so many processes going on in an ecosystem that one must start by subdividing them into groups. This is done with regret since they are all closely interrelated, but the advantages gained outweigh the disadvantages, providing we remember that we are doing it purely for our convenience and that the ecosystem doesn't know about it!

Four groups of processes as set out by Ovington (1962) are:

I The Production of Matter—Organic Matter Dynamics

II The Flow of Energy — Energy Dynamics

III The Flow of Water—Water Dynamics
IV The Cycle of Nutrients—Circulation of Chemical Elements

Another one—the changes in the numbers of plants and animals, or Population Dynamics—will be considered in the next section.

The benefits of working in terms of processes are that

(a) the factor of time is brought in at all levels—one studies rates, not quantities,
(b) there is a clearly formulated framework of thought which (while not restrictive) enables one to work on even small parts of the system and not lose sight of the whole,
(c) the processes are sufficiently well defined to allow quantitative measurement.

Organic Matter Dynamics

A forest ecosystem such as the hard beech *(Nothofagus truncata)* site being studied in the Hutt Valley (Miller 1963) is a massive thing. It contains 125 tons/acre of plant biomass and 20 tons/acre of soil organic matter. However, it is low on the animal side with certainly much less than 100 lb./acre.

Compare this with a pasture ecosystem which might have a plant biomass of less than 1 ton/acre and a similar biomass of animals.

If we consider processes rather than the ecosystems themselves the differences are less. The forest each year adds a ton/acre of wood to the trees and drops 3 tons of litter back to the soil. The pasture produces a roughly similar amount of plant biomass, some of which is retained in the animals and the rest returned to the soil.

Of the many measurements that might be made the *net primary productivity* (the increase in biomass/acre/year) is possibly the most useful for, using it, ecosystems of all kinds may be compared factors limiting growth found, improvements evaluated and, if necessary, the performance of the system expressed in economic terms. Other important aspects include litter formation and decomposition, animal returns, pasture consumption by other organisms, the whole complex of seasonal changes and the effects of management (Brougham, this volume).

Changes in organic matter are governed by the other groups of processes.

Energy Dynamics

The flow of energy from the sun and its utilisation and dissipation in the ecosystem is fundamental to ecosystem dynamics. The energy is used for evaporation of water and for heating, some is reflected, some retransmitted and a very important fraction is transformed into chemical energy by photosynthesis and stored in plant tissues.

In forests much energy is stored in timber and when the timber is harvested this is immediately available. In a pasture ecosystem the plant material is eaten by an animal which in turn is eaten by human consumers with very large (say 90%) losses at each stage. The efficiency of utilisation of energy is therefore very much lower, although not nearly as low as in, say, a marine ecosystem where the energy pathway may have many more steps.

As with other processes in ecosystems energy flow lends itself to quantitative treatment. In our hard beech project measurements are made of solar radiation, light reflected and transmitted by the canopy, energy content of the vegetation, respiration and photosynthesis, soil respiration, litter breakdown, temperature—all of which help to build up the picture. In pasture systems a great deal more work has been done than in forests (Mitchell, this volume).

Water Dynamics

Thousands of tons of water move into each acre every year from the atmosphere and are evaporated, transpired, run off or run through the soil into the drainage system. Water is an important carrier of nutrients, and a major user of energy. Again, the components of the cycle may be measured. There is an upsurge of interest in this kind of work with the approach of the International Hydrological Decade and the projects to be undertaken in New Zealand should make a real contribution to ecosystem studies.

At the Taita Experimental Station we are at present designing two flow recorders for pasture catchments to compare water flows with those occurring in native forest and exotic forest catchments. These and associated equipment will supply information about the large scale flow of water—precipitation, evaporation, transpiration and run off.

For pasture studies, of course, much more is needed than this. In particular measurement of water movement within the soil and within the pasture canopy is essential. Some work of this kind is described elsewhere in this symposium.

Circulation of Minerals

To a soil chemist mineral circulation is of particular interest. Its study involves estimating (i) the quantities of plant nutrients supplied by the soil to plants and returned to it by plants, (ii) the contribution from the atmosphere, (iii) from weathering and (iv) the losses to drainage. As this kind of work goes on it becomes more and more obvious that it is as impossible to study soils without the rest of the ecosystem as it would be for, example, to study aerial parts of plants but not the roots and soil.

In studying the circulation of minerals the forest ecologist has the advantage over the pasture ecologist in that the return mechanism is much more clearly defined. In our beech forest site by measuring the movement of elements from the atmosphere in leaf wash (the rainwater reaching the forest floor) and litter fall, in the trees, and in drainage water out of the soil, we are starting to learn something of the needs of plants and of the capacity of the soil to supply them.

In pasture, of course, this kind of study presents real problems. It is, for example, 60 years since the importance of leaf wash in the chemical composition of pasture was shown (le Clerk and Breazeale 1908) but so far, I do not think there have been any field measurements. When the grazing animal is included the problems become even more complex. However, they are being tackled. A great deal can be learned, for example, from regular sampling and analysis of pasture and soils.

Saunders *et al.* (1963) have shown that although Taranaki yellow-brown loams are quite capable of supplying sufficient phosphorus for pasture during the spring flush the supply must be supplemented to keep growth rates high in other periods.

In Hawkes Bay Metson (pers. comm.) has found that different soils have different capacities for maintaining element balances in pasture. In places, spring and autumn pastures may have abnormally high levels of some elements and low levels of others, so much so that they appear at times to be implicated in the ill health or even death of stock.

This sort of work emphasises the importance of current interest in pasture quality. For optimum growth animals as well as plants require food of the right composition throughout the year. This is particularly so in times of stress such as lactation. Then the soil, also, is under stress to supply rapidly growing plants; and limitations are likely to make themselves felt. The ecosystem must be considered in all its aspects and element movements thoroughly understood so that imbalances may be corrected by additions of nutrients to the cycles at the right time and in the right amounts.

Another aspect of the mineral cycle was discussed by Healy at this meeting. Reference might also be made to a study in which measurements were made of both chemical and biological aspects of a pasture development sequence after scrub burning (Miller, Stout and Lee 1955-1962). This showed that the unproductive energy released on burning was accompanied by a large and very productive release to the mineral cycle of large amounts of soluble plant nutrients. At the same time there were substantial changes in the soil fauna and microflora and these continued to change as the new pasture ecosystem was established. One thing was clear and that was that the soil biology and chemistry were closely related to each other and to the changing vegetation and that study of only one aspect would have given a very incomplete picture of the changes taking place.

THE ECOSYSTEM ITSELF

What is present?

Although ecosystem processes, like soil processes, have proved a fruitful field of study, the ecosystem itself—the soil, the plants and the animals that are there—must also be taken into account. As Southern (1965) has written:

> ". . . the smoothed picture of energy flow and productivity studies gives no indication of the complexity and pattern of a community's organisation and, therefore, no information about the components of the production and the paths through which energy flows, nor about their reactions to interference or exploitation".

How is it changing?

Consideration of the stability of ecosystems, or of any changes in them that come about naturally or by management, introduces another facet, that of population dynamics. At any given point in time it is "what is present" that is significant, but over a period changes in numbers and species of plants and animals must be taken into account.

In a managed pasture ecosystem with changes occurring all the time in animals and plants, studies of population dynamics are essential if full understanding is to be achieved. And it is not only changes in the main components that are important: not only should earthworms and grass grubs be studied as well as sheep, but weeds are involved in the system as well as grass and clover.

CONCLUSIONS

a. For studies of pasture production and its utilisation the ecosystem is the natural unit of study.

b. A particularly significant expression of the ecosystem is found in ecosystem processes.

c. However, the nature of the soils and the species of plants and animals present in the ecosystem are also important.

d. So are the changes that take place in the numbers and species of organisms present.

e. These three, the ecosystem itself, the dynamics of its populations and the rates of its various processes provide a conceptual framework which allows the whole system to be kept in view while detailed studies are carried out.

f. The compenents and processes may be measured quantitatively and it is possible to take into account not only natural changes but also changes introduced by man.

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STRUCTURE OF VEGETATION IN RELATION TO ENERGY EXCHANGE

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New Zealand has a proud ecological history. Particularly as far as our vegetation is concerned, ecology has gone through phases similar to those in most countries of the world. The pioneers described the general patterns of the communities and set in perspective the picture for the country as a whole. Then came more detailed description of particular situations, and the introduction of quantitative measurement techniques. The latter allowed standardised definition of what is present at a site and measurement of differences between sites. The result has been a generally satisfactory answer to the question of "what species are present and what trends are occurring"?

Next came the question of why certain species are present and why the trends are occurring. It is with the treatment of these questions of "why" that vegetation ecology, and probably many other branches of ecology as well, has become notable for its imaginative speculation and for the low quota of hard facts on which those speculations are based. Remembering Kelvin's dictum that an issue does not become science until you can measure it, we have here a reason for the relative decline in the status of plant ecology, within the scientific community within the last 30 years.