1.1 Introduction to soil fertility

What is soil fertility?

The fertility of soil can be considered in different ways, depending on land use. In intensively managed agricultural and horticultural systems, and even in forestry, soil fertility can be defined in terms of the value of products produced relevant to inputs used (including economic aspects of nutrient budgeting). Alternatively, the emphasis may be on quality or productivity.

i.e. The fertility of soil is related to its capacity to produce a product.

In many natural ecosystems, the value of land use may not be clearly defined, and a different definition of soil fertility may be more suitable.

i.e. The fertility of soil is related to its capacity to support a particular natural community of plants.

Another view might emphasize the concept of sustainability.

i.e. The fertility of a soil is related to its capacity to maintain consistent output with minimal input.

Thus, the concept of soil fertility is most useful when it is used in a specific context. However, in all contexts, soil fertility depends on **physical**, **chemical** and **biological** characteristics.

When soil fertility is considered in terms of the highest practical level of productivity, the focus is mostly on physical and chemical aspects of soil. It is important to note that some aspects of the biological component of soil fertility can be overridden by addition of fertilizers, but this is not a simple phenomenon, because increased plant growth associated with addition of fertilizer can increase other aspects of the biological activity in soil. The background to these apparently contradicting statements will be addressed later.

When sustainability of the soil resource is emphasized in the context of soil fertility, biological components may become more relevant because long-term productivity is taken into account. A change in focus from the highest practical level of productivity to a lower, profitable and persistent level of production has the potential to depend to a greater extent on soil biological processes.

In a natural ecosystem, such as a forest, definitions of soil fertility based on commercial production as defined above may be misleading. For example, soil in the jarrah forest of south-western Australia is highly fertile when defined in terms of production of jarrah trees (*Eucalyptus marginata*). They do not grow naturally anywhere else. However, the same soils are very infertile in terms of the nutrient requirements for agricultural plants. Jarrah trees grow very slowly and produce a timber of a very high quality. They are well adapted to growing on then local high phosphate-fixing soils. The same soil is highly unsuitable for growth of agricultural plants without addition of large quantities of phosphorus and other nutrients, including nitrogen.

This difference between jarrah and agricultural plants is extreme, but it illustrates an important distinction between agricultural and native plants, which differ in:

- their nutrient requirements, and

- their ability to take up nutrients from low levels in soil.

Much is already known about these processes, and although plant nutrition is not discussed in detail here, it is obviously very relevant to a discussion of soil fertility.

To extend this analogy further, the addition of soluble phosphate fertilizer to jarrah forest soil would increase the chemical fertility of soil and the rate of growth of jarrah trees. As a result, the quality of wood produced may be different to that formed more slowly under natural conditions. Furthermore, fertilizer would also alter the growth of other plants in the jarrah forest community and the relative abundance of forest understory plant species would eventually change. While intentional fertilization of a natural forest is not normal practice, it occurs where there are excess nutrients (such as nitrogen) in the atmosphere. Thus, the principles of plant nutrition in relation to soil fertility apply in all environments.

In a sustainable agricultural or horticultural system, soil fertility can be considered in terms of the amount of input relative to the amount of output over a long period, using a budgeting approach. This definition is different to one that defines fertility in relation to a maximum level of productivity in the short-term, or at one point in time. A definition that focuses on short-term productivity is based on the capacity of soil to immediately provide plant nutrients. A definition of soil fertility that is inclusive of sustainable land must consider the three components of soil fertility (biological, chemical and physical) equally, as is discussed below.

What are the components of soil fertility?

There are three main components of soil fertility - physical, chemical and biological (Abbott and Murphy 2003). The level of soil fertility results from the inherent characteristics of the soil and the interactions that occur between these three components. Most characteristics that contribute to the fertility of soil, such as soil pH and the susceptibility of the soil to compaction are dependent on the constituents of the original parent rock. Subsequent events, including the growth of plants and addition of fertilizer, modify the soil characteristics and alter its fertility. For instance, the original soil pH can be modified by legumes which increase soil acidity (i.e. decrease soil pH).

Pedology is the study of the formation of soil and the physical process of soil formation plays a major role in soil chemical fertility. For example, the relationship between pedological characteristics of soil and soil chemical fertility are clearly demonstrated for the lateritic soils of jarrah forests in south-western Australia (Robson and Gilkes 1981).

The soils formed on these laterite soils have low levels of chemical fertility (especially phosphate, calcium and magnesium) because of the chemical characteristics of the parent rock. These low levels of nutrients lead to either low or slow productivity of plants and to low levels of organic matter returned to the soil. Overall, biological activity is low because of the low level of organic matter, and many biological processes proceed at a slow rate.

It is useful to understand the origins of soil because it helps in predicting how soil disturbance influences the three components of soil fertility. From the pedological characteristics of lateritic soils in the jarrah forest of south-western Australia, we can predict that they will be chemically infertile for agricultural and horticultural plants. When the soil is disturbed during mining for bauxite, the low level of chemical and biological fertility is further reduced because the topsoil is lost. This is because most of the nutrients and soil organisms occur in the topsoil. If fertilizer is added, it rapidly restores the nutrients to a large extent and additional seeds can be sown to regenerate the vegetation but soil biological processes take longer to re-establish.

Pedology is useful for predicting the following:

(i) where problems for growth of introduced plant species are likely to occur,

(ii) where particular crops will grow best,

(iii) where soil degradation is most likely to occur, and

the requirements for re-establishing plant communities in highly disturbed environments such as mine sites.

The biological components of a soil which influence its fertility include many different types of organisms: microorganisms (bacteria and fungi), animals (microfauna, mesofauna and macrofauna) and plants. These organisms range in size from less than a micrometre to more than a metre. Most are only visible with a microscope.

These examples illustrate the considerable difference in dimensions of organisms that inhabit the soil. The size range depends on the species. For example, one species of earthworm from south-eastern Australia is more than a metre long, although most native earthworms in Australia are much smaller than this (several centimetres). Earthworms common in agricultural soils fall into the range of 5 to 15 cm in length. In contrast, most bacteria are of a much smaller size, about one micrometre. When bacteria are grown on agar plates in a laboratory they are usually slightly larger than the same organism would be in the soil. This is partly because artificial growing media contain much greater quantities of nutrients than might naturally occur in the soil.

Fungi usually form thin threads of hyphae in soil that may be many metres long. Hyphae of some fungi aggregate into rope-like structures or highly structured mushrooms and other types of fruiting bodies. The aggregation of hyphae in this way commonly occurs in natural ecosystems where it is unlikely to be disrupted by physical disturbance.

How are the components of soil fertility linked?

The three components of a soil influence each other to varying degrees. For example, the addition of plant residues to soil can alter nutrient and water-holding capacity of soil and this in turn can alter the chemical environment of soil organisms. Inter-relationships between the physical, chemical and biological components of soil create the environment of soil organisms.

It is likely that the physical nature of the soil has the most impact of the three components on soil organisms, whereas soil organisms have a greater effect on the chemistry of the soil than on the physical components. The physical and chemical components are also linked by processes such as nutrient adsorption and desorption from surfaces and nutrient transport through soil. However, there are many differences between soils depending on their origin that could influence the strength of these inter-relationships.

Soils are subjected to a variety of types and frequencies of disturbance and these disturbances can alter the linkages between the three soil components.

When soils are disturbed, the effects on soil fertility are complex. This is illustrated below by identifying the effects of cultivation on soil fertility. These effects may be either *direct* (acting on each component separately) or *indirect* whereby a change in a physical aspect leads to a change in the chemical or biological aspect or vice versa.

Direct effects combine to modify the soil as a place for plants to grow, and the growth of plants may consequently be different to that of plants growing in a similar but uncultivated soil. In other words, cultivating the soil can alter plant growth via a set of complex pathways that involve physical, chemical and biological processes. Thus, many indirect effects of cultivation on soil biological processes are possible.

Ecosystems fall into a continuum in degree of disturbance. Soil processes are similar in all environments, but the relative importance of different processes changes with soil type, climate and topography. Organisms with similar functions usually occur in most soils. Thus, life in different soils has underlying similarities, although the types of organisms present usually differ.

How is soil fertility measured?

Three major *physical components* of soil fertility are soil texture, soil structure and water holding capacity. Information is required about what sort of range in measurements of factors such as these is appropriate for a particular soil type.

The *chemical components* of soil fertility that are most relevant to land management include acidity, alkalinity, salinity and nutrient status. However, the quantity of nutrients in soil is not always related to its fertility as other factors may limit plant growth. An understanding of the methods used in soil and plant analysis is necessary to evaluate the relationship between nutrient levels in soil and soil chemical fertility.

Biological components of soil fertility are generally more difficult to measure than both soil chemical and physical components. Information about the abundance and types of organisms present is not very useful unless the relationship between the number of organisms and aspects of soil biological fertility is also known. Bioassays of some plant pathogens or beneficial organisms can give an important indication of the possible positive or negative contribution of these organisms in soil. This information is based on research that relates the number of organisms in the bioassay to the expected level of disease in the field. Such relationships are not always simple, and may not be the same for different soil types.

One approach to assessing biological components of soil fertility is to determine the number or activity of groups of organisms that perform similar functions. Assessment of functional groups of organisms may be more relevant to some aspects of soil biological fertility than identification of individual organisms.

Summary Points (1.1)

- Soil fertility reflects the physical, chemical and biological state of soil.

- Soil fertility can be defined in relation to the plants that grow naturally or are introduced into soil.

- Knowledge of the origin of soil helps to predict the level of soil fertility prior to land management.

- Soil disturbance alters the physical, chemical and biological components of soil fertility either directly or indirectly.

- Assessing the biological fertility of soil is not simple and this book provides an overview of why this is so.

For additional reading on soil fertility and parent material, check out pages 11-14 in the document from the following link: nb9538_report.pdf