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Tropical soils: importance, research and management

To sustain and improve food production to meet future demands we need to pay closer attention to the way in which soil resources are managed.

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Soil supports the growth of plants which supply the world with food, biomass and renewable energy. It provides habitats for biodiversity, species and genes, and is a major source of raw materials. It also stores, filters, and transforms nutrients, substances and water, and it acts as a carbon sink in global climate regulation.

Soil fertility

Soil fertility refers to the ability of a soil to provide crops with essential nutrients for growth.

The factors that contribute to soil fertility are:

- infiltration and drainage of water;
- content of organic matter;
- soil structure;
- active soil life;
- exploitable soil depth;
- mineral content;
- soil acidity (pH);
- content of available nutrients;
- nature of parent soil;
- ground water

Many methods have been developed for the evaluation of soil fertility. These fall into several clusters:

- Plant performance trials including field trials and pot cultures to assess growth, development, toxicity and nutrient deficiencies.
- Chemical analyses of plants, including total elemental analyses and plant tissue analyses.
- Chemical and biological analyses of soils: pH, ammonium and nitrate nitrogen, population of soil microorganisms such as nitrifying bacteria, free living nitrogen fixing bacteria, symbiotic N-fixers, bacteria and mycorrhizae.

Field tests are used to assess manures, composts, fertilizers, water consumption, irrigation systems, etc. Important features in such tests are: site selection, layout, test phases, qualitative determination and quantitative determination. Results may be quantified by plant growth, increase in biomass, time to fruit-bearing or marketing, fruit yield, profitability, etc.

Soil quality

Soil quality can be defined by how well a soil performs the functions of maintaining productivity and biodiversity, nutrient cycling, and providing support for plants and other structures (Toth *et al.*, 2007). Soil quality can be assessed using a wide range of indicators, but a smaller set of indicators may be more practical and still provide the necessary information needed (Kostov & Lynch, 2002; Lima, A.C.R.,

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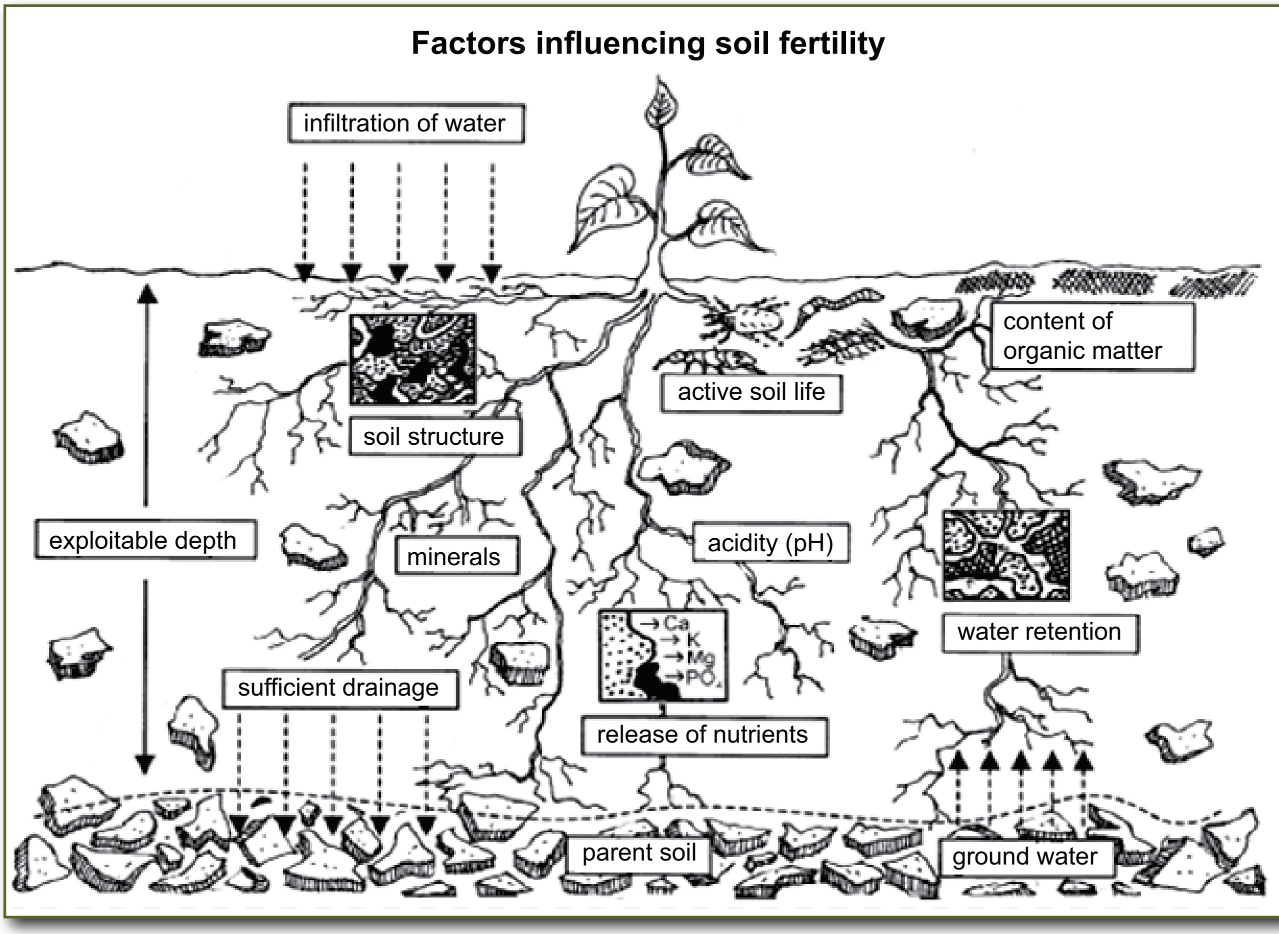

Figure 1. Factors affecting soil fertility

Figure 2. Soil with good fertility

Brussaard, L., Totola, M.R., *et al*., 2013). A soil quality index combines several indicators into one value by prioritising or weighting them according to their importance.

Soil degradation

A good soil provides plants with nutrients, water and oxygen to support plant growth. Direct degradation threats to soils are manifold, among which are erosion, salinization, compaction, loss of organic matter, landslides, contamination and sealing. Soil properties affected by soil degradation are nutrient content, porosity, soil biomass, water holding capacity, topsoil depth, acidity and salinity. The main processes causing soil degradation are: nutrient depletion, soil compaction, soil organic matter depletion, soil erosion, acidification, salinization, and accumulation of harmful components. It is possible for soil to be degraded beyond recovery, but it is also possible to keep soil productive indefinitely through appropriate measures (Kostov & Lynch, 2002).

Soil degradation has serious economic consequences: lower return of investments in the agricultural sector, insufficient quantity and quality of food, higher food prices, increased government expenditure on health, reduced government revenue due to reduction in collected taxes on agricultural goods, migration of rural people to urban areas, and increased sedimentation of dams due to soil erosion.

Integrated nutrient management

In agricultural ecosystems, plant products are constantly removed and exported together with the nutrients they contain. As a result, the amount of nutrients in the system is reduced at every harvest. Integrated nutrient management is a way to combat nutrient depletion by combining organic and inorganic (mineral) methods of soil fertilization with physical and biological measures for nutrient, soil and water conservation. In integrated nutrient management, the following principles are important:

- Maximization of the use of organic material;
- Balanced use of inorganic fertilizers and
- Minimization of losses of nutrients.

Local adaptation is always necessary because of variations in resources and conditions in different places. For example, there are significant differences in the organic materials available, in the price of inputs and outputs, the cost of labor, and the level of farmers' knowledge. Also, the depth of soil varies according to location.

Maximization of the use of organic material

Agriculture in the tropics is highly dependent on the release of plant nutrients from soil organic matter and from organic manures. Soil organic matter plays a critical role in maintaining soil fertility, water holding capacity, cation exchange capacity, acting as buffer against pH changes, and reducing surface crusting. Organic fertilizers produced locally should be cheaper because of lower transportation costs as compared to imported fertilizers. Other efforts to promote so-called Low External Input Agriculture include the use of cover crops, animal manure and improved fallows (Kostov *et al*., 2002).

However the following limitations have been observed with organic fertilizers:

- Too low quantities are available to meet requirements;

- Only a limited amount of phosphorus is supplied;
- Application of manure is much more labor intensive;
- Low N content (1–3%) as compared to inorganic fertilizers;
- Release of nutrients not well-synchronized with plant demands for nutrients;
- Great variation in the quality of organic fertilizers.

Generally, low quality organic fertilizers/materials, such as roots and crop residues, can be used as surface mulch to protect soils from erosion and for weed control, and to improve soil organic matter balance (Kostov *et al.* 2002), but high quality organic fertilizers can be used as a direct plant nutrient source. However, Malaysian composts do not have enough P to replace mineral fertilizers (Wan Rashida *et al.*, 2004) and cover crops do not supply sufficient phosphorus for plant needs.

Balanced use of inorganic fertilizers

Inorganic fertilizer use varies greatly among continents. In 1994/5, fertilizer use per hectare averaged more than 216 kg in East Asia, 77 kg in South Asia, 10 kg in Sub-Saharan Africa and 65 kg in Latin America (Kostov, O. 2008; Vladeva, D. & O. Kostov 2002; Wan Rashida Kadir, A. Rozita, K. Hoi, and O. Kostov 2004).

Inorganic fertilizers have an immediate effect and can be applied to synchronize with plant growth.

Inorganic fertilizers should be combined with organic material. In Malaysia, well-matured composts using sludge and POME (palm oil mill effluent) have good levels of available N and K which can substitute for or complement inorganic fertilizers. Such composts reduce the acidifying effect of inorganic fertilizers and also improve soil physical characteristics.

Low levels of nitrogen and phosphorous often critically limit crop production in the tropics. Composts and organic fertilizers contain a low level of P and for this reason application of inorganic P is very important. Rock phosphate is a source of P but the P is released slowly. Single, double and triple superphosphates are more suitable because they release P faster and are water soluble. Nitrogen fixation is also improved if P deficiency is removed.

The value cost ratio (VCR) is the value of yield increased due to fertilizer application divided by the fertilizer cost. This value must be two or greater to cover risk. In the humid tropics, application of inorganic fertilizers is very risky because one episode of heavy rain can remove all applied fertilizers. This is the reason why in Sabah (Malaysia) during December and January, farmers avoid applying fertilizers. Adjusting fertilizer application according to weather forecast can greatly increase profitability. Another technique is point application, which dramatically increases fertilizer use efficiency.

Minimizing losses of plant nutrients

The loss of nutrients from the agricultural system is not confined to removal of harvested products, but can also be the result of soil erosion, gaseous losses and leaching. Soil erosion can be in two forms: water erosion and wind erosion. To maintain soil quality these losses have to be restored with fertilizer application to maintain balance.

Soil erosion results not only in nutrient loss but also in reduction of topsoil depth and water holding capacity. Eroded materials contain the finer particles of the soil that are rich in nutrients. Soil erosion is related to such parameters as topsoil depth, rooting depth of plants, type of crop cultivated, distribution of soil nutrients in the soil profile, water holding capacity of the different soil layers, and amount and intensity of rainfall. Mianushev (2013) has reported strong reduction of soil erosion by application of inorganic and organic materials due to root and shoot mass increment.

Conservation cropping

The Natural Resources Conservation Service of USA is promoting a Conservation Cropping Systems Initiative (CCSI) that combines a range of practices including zero tillage, cover cropping, crop rotation, mulching, etc. The aims are to simultaneously improve soil quality, increase water infiltration; reduce water runoff and nutrient losses, save energy, reduce pesticide application, reduce inorganic fertilizer application, and improve weed control. In the corn belt of the USA, one extra inch of water in August saved through soil health practice can mean an extra 20-40 bushels per acre in corn yield. Indiana State is a leader in CCSI (http://www.nrcs.usda.gov) and this has resulted in higher crop yields, healthier soils and a healthier environment. The Indiana model could serve as a model for other countries.

Management of low productive soils

There are low productive soils which need the application of specialized technologies.

Heavy metal contaminated soils: There are soils which, as a result of mining activity, have lost their fertility. Usually these soils are acidic and contaminated with more than one heavy metal. To rehabilitate such soils, CaO or $CaCO_3$ may be applied according to measured acidity. Microbial diversity has to be recovered by treatment with 20 cm compost layer (Kostov & van Cleemput, 2001). Then suitable grasses have to be used to cover the treated soils to prevent erosion.

Salinized soils may be managed by leaching and application of gypsum.

Strongly eroded soils can be planted with nitrogen fixing plants and grass mixtures but before planting they should be treated with a big amount of compost or manure.

Weathered soils, which are typical of tropical conditions such as those in Malaysia, can be treated with alkaline solution of oil palm bunch ash to neutralize exchangeable Al and then compost is applied to promote soil microbial diversity and improve the structure of the soil. In a study that I carried out in Belgium using: 4 Indonesian, 4 Malaysian and 4 Belgian soils with the same acidic pH of 4.5, I found that Malaysian and Indonesian soils showed exchangeable (toxic) Al but Belgiun soils despite having the same acidity did have exchangeable Al due to its high organic matter content (2.8%). Acidified soils should be treated with CaO plus organic fertilizers such as composts to improve their

Figure 3. Turning windrows to optimize microstructure, O_2 and moisture content of compost.

structure and remove toxic (available) forms of heavy metals.

Polices for soil fertility management. Fertilizer usage should be accompanied by recycling of organic materials to ensure soil microbial diversity (Gardi *et al*., 2013), to avoid pollution of ground waters and rivers, waterlogging and salinization of irrigated land, to reduce human health problems related to pesticide use, to reduce CO_2 and N_2O emissions that cause global warming, and to sustain soil quality for future generations.

Because private farmers are focused on short term local benefits, the process of creating an extensive, more sustainable and more productive agriculture system requires public action along many paths. An investment that may give too little return to be of interest to the individual farmer may be beneficial to the public. For example, the benefits to society of erosion control programs can be related to reduction of poverty, prevention of siltation of dams, and destruction of roads.

Political/economic factors such as prices of inputs and outputs, access to credit and related interest rates, and nature of infrastructure and markets, are of vital importance for soil fertility management. Investment in soil fertility management will be increased if there is a policy to reduce dependence on inorganic fertilizers by promoting the making of composts