SOIL ORGANIC MATTER: A REVIEW OF RESEARCH RESULTS

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1. The Role of Soil Organic Matter

Soil organic matter comprises humic material (mostly negatively charged colloids, bound to clay) and plant debris in various stages of decomposition.

Soil organic matter is important in determining soil physical structure, chemical properties, water relationships and biological activities. In addition, organic matter lying on or close to the soil surface confers particular properties that can affect the fertility and productivity of the soil mass.

a) Soil physical properties

- Porosity and infiltration rates for water are increased by organic matter. Infiltration rates exceeded 12.5 cm cm per hour in mulch experiments at Samaru, northern Nigeria (Lawes, 1962). Runoff from soil liable to encrustation (capping) by raindrop impact is reduced by surface OM, and close linkage has been noted between increased infiltration and erosion control on fine sandy soils in East Africa (Russell, 1973).
- Similarly, drainage of clay soils is improved by raising OM content.
- Water-holding capacity is enhanced, although availability of water is increased only in sandy soils, due to the tight binding of water to OM, especially in peat soils.
- Evaporation losses are reduced by surface OM.
- Aeration is improved by greater porosity associated with soil aggregation.
- Physical tilth is improved by soil particle aggregation, with the result that timing of cultivations is rather less dependent upon ideal weather and soil moisture conditions, and farmers' tillage bottlenecks may be relieved by end-of-season or early-season ploughing.
- Maximum soil temperatures are lowered, particularly by surface OM, giving improved germination and seedling establishment in lowland tropical situations - whether this is important for beans in e.g. Somalia or Mauritius is not known.

b) Chemical properties

- Cation exchange coefficients (CEC) are higher in soils with more humified OM, and the negatively charged organic colloids generally have a higher CEC per 100g than the clay portion of the soil. However, the clay component can be dominant in determining overall CEC of soil. A survey of soils in Ethiopia indicated that average OM content was highest (8.7%) and contributed the most (25.8%) to total CEC in the dark brown clay soils; although the OM portion of the vertisol group had higher average CECs (288 me per 100 g against 98 me per 100 g for the dark brown group), it was the clay portion that accounted for most of the very high CEC of the vertisol group (Murphy, 1963).

- Buffering capacity is provided by the colloidal properties of humus and clay, and is highest in fine textured and organic soils. This prevents damage to crops as acid and base composition of a soil changes during the season.
- Chelation of metallic ions by humic colloids can make micronutrients more available, provided that they are not too strongly bound or fixed.
- OM is an important source of plant nutrients, particularly nitrogen: one-third to one-half of cereal crop N is left in residues at harvest, and P, K, Ca and Mg are also commonly available. Nutrients are released by mineralisation at the start of the rains. Nitrogen cycling in agricultural ecosystems was recently reviewed by Wilson (1987).

c) Biological effects

- OM enhances the level of microbial activity within the soil. Provided other factors (such as moisture) are not limiting, rates of decomposition of plant residues and mineralisation of nutrients increase with OM content. The resultant increase in soil aggregation leads to general improvement in soil structure.
- Crop root penetration is facilitated by high OM content and low bulk density of soil. Greater rooting depth increases the available volume of soil water; greater root development, both superficially and deeper in the profile, increases the uptake of P.

2. Interactions of Management Practices with Soil OM

a) Implications of seasonal effects on decomposition

Under steady environmental conditions, net mineralisation of soil N is at a low level. OM decomposition rates are at least doubled by each 10° C rise in temperature (in USA soils), and are promoted by a soil moisture regime between wilting point and field capacity. (Soil micro- and macro-organisms and OM composition are the other factors controlling residue and OM decomposition).

Interruption of soil biological activity, most commonly by dry onditions, is usually followed by stimulation of mineralisation of N in easily decomposable humus. This leads to the nitrogen flush at the start of the rains, first demonstrated under field conditions in Kenya by Birch (1960a) and now sometimes referred to as the "Birch effect". Its widespread occurrence in different soils and climates of East Africa was confirmed by Semb and Robinson (1969). During periods of regular rainfall soil nitrogen levels remain low, due to plant uptake and to lower rates of mineralisation and nitrification. Net mineralisation resumes as the rains end and nitrification continues as long as soil is moist.

The initial flush of N is highly leachable. Taking advantage of showers before the main rains to plant early, or dry planting ahead of the expected start of the rainy season, enables a quickly growing crop to benefit from this flush. As the amount of N mineralised in this flush is greater the longer the dry season (Birch, 1960b), early crop establishment may be particularly beneficial in semi-arid monomodal rainfall areas such as the Ethiopian Rift Valley and Southern Africa production areas for beans.

Bare fallows, and soil having an exposed surface during the dry season (e.g. due to crop removal or livestock grazing), also tend to have high levels of nitrate-N at the top of the profile due to more humus decomposition. At Kawanda, Uganda. levels of 100 ppm in the top 15 cm of fallow soil were recorded by Griffith (1951) and of 200 ppm in the top 5 cm by Mills (1953).

Minimum tillage techniques are used traditionally to permit early planting in some areas of Eastern and Southern Africa (Kirkby, in press). These techniques include pre-digging of planting holes. However, constraints of labour availability and the weakening of draft animals by dry season feed shortage severely limit many small farmers' ability to do this (Collinson, 1984).

Even in higher rainfall areas alternating wet-dry conditions on steep hillslopes lead to a series of small N-flushes. In one such situation in eastern Zaire, farmers cut the growth of weeds and incorporate it lightly before planting beans. During later weeding of the bean crop, "good" weeds, recognised as those which are easy to remove and which decompose rapidly, are selectively applied as green manure around coffee and banana plants at a time when soil nitrogen levels have decreased (Fairhead, 1987).

Crops that are traditionally planted late in the rainy season, such as cotton, sunflower, sesamum and chickpea in Eastern and Southern Africa, develop on residual soil moisture and cause more rapid drying of the soil profile. Following crops might be expected to benefit from a larger flush of N, although this aspect of annual crop rotation does not appear to have received attention in the region.

b) Nutrient cycling in cereal-legume systems

Cereals usually benefit slightly or not at all from nitrogen fixed in the root nodules of intercropped legumes. Rather, the benefit usually accrues to the subsequent cereal crop. In this situatiion soil OM plays an important intermediate role in this transfer. Kang's (1987) review of N cycling in these systems indicates that much less attention has been paid by researchers to the efficiency of the transfer process than has been paid to increasing the N supply through BNF.

c) Minimising losses of OM and nutrients

Soil erosion causes a disproportionate removal of the OM portion; hence all practices that minimise erosion contribute to the maintenance of soil properties conferred by its OM content. Bean crop management trials at Nazret, Ethiopia showed that the innovation of ridge planting was more effective than traditional broadcast planting on the flat in controlling erosion provided that heavy rain did not fall before ridges had stabilized. However, in a year when heavy rain fell only 13 days after ridging, the traditional local bean practice was much better, and as good as natural grass cover in preventing runoff and conserving soil and OM (Table 1; Abiyo, 1987). Farmers' practice in the Nazret area of not weeding beans has some mitigating effect in further reducing erosion early in the season.

Table 1: Mean Soil Moisture, Organic Carbon, Bulk Density and Infiltration Rates for Bean Planting Methods at Nazret, Ethiopia. 1981 - 82.

Treatment	Soil moisture (%)	Organic carbon (%)	Bulk density (g/cc)	Infiltration rate (mm/h)
Ridge planted beans	11.81	0.47	1.24	248
Broadcast beans	12.18	0.87	1.35	260
Bare fallow	9.92	0.76	1.32	224
Natural grass cover	12.34	0.86	1.29	196

Source : Abiyo (1987)

Leaching of nitrate in higher rainfall areas can be reduced by early planting, cereal-legume intercropping and relay cropping practices that involve a longer period of rapid crop uptake and dense root development. Cereals and legumes are complementary in mixed cropping patterns; under sole crops in Senegal, nitrate leaching was found to be higher under groundnuts than under millet (Gigou et al, 1985).

Lowering soil temperature, by crop cover or mulching, reduces OM decomposition rates but will not be an important factor in highland bean production areas.

d) Source of OM

Plant roots are more effective than top residues in promoting the beneficial properties of humus. This difference is due to the more intimate contact of decomposing roots with the soil, producing gums that are protected from further microbial action and therefore are more stable; aggregate formation from top residues is promoted by fungal mycelia which later break down together with the aggregate. Grass roots, being fine, can be suitable for short-term planted fallows to restore OM, although they do not act as a mineral pump to the same extent as a deep-rooted tree and do not have the N-fixing ability of legume fallows.

Top residues of different species vary in their effectiveness in cycling nutrients and maintaining humus content. High quality, rapidly decomposable residues are those which have high N and P contents, high concentrations of readily metabolised sugars, low liguin contents and absence of allelopathic compounds (Swift, 1988). These aspects are important in selecting green manure crops. The carbon: nitrogen ratio of residues can be useful in predicting the rate of decomposition, and low-nitrogen cereal residues may not contribute to an expected seasonal nitrogen flush. Parr and Parendick (1978) caution against relying upon the C:N ratio as this "says nothing about the availability of the C or N to microorganisms".

In a stable, natural system, different sources of OM contribute to soil fractions that decompose at different rates, and which tend to lead to a more constant availability and cycling of nutrients (Swift, 1988). This effect is distinct from another feature of the use of deep-rooted trees and shrubs in improved fallow and agroforestry systems, which is to pump nutrients and especially basic cations from below crop rooting depth (Greenland, 1975).

Application of large amounts of organic residues can have long-lasting effects upon OM accumulation in soils at high altitude, as reported from Madagascar (Gigou et al, 1985). In most studies, however, OM levels have not been affected in the long term by application of OM.

e) Management of crop residues

Between one-third and on-half of cereal grain crop N remains in crop residues at harvest. Other nutrients, particularly P, K, Ca and Mg, can also be recycled through management of crop residues in various ways:

- by burning: virtually all N is lost, as well as the potential anti-erosion and soil-conditioning properties: however, little labour is required.
- by use as mulch: additional benefits of OM for soil surface properties have been mentioned above; no-till seeding through the mulch, and control of perennial weeds, can present problems. Mulching is discussed in part 4 of this paper.
- by incorporation of stover: short term storage of OM increases as the residues decompose, but, in general, cultivations lead rapidly to a decline in OM; in temperate zone agriculture, conventionally tilled fields have a similar average OM content to no-till but effects are not concentrated near the soil surface (Elliot & Papendick, 1986); incorporation is labour-intensive but is used in some traditional systems such as the Sukuma split-ridge system and the matengo pit cultivation system of Tanzania.
- conversion by livestock: where livestock are closely integrated with crop production (e.g. much of Ethiopia, Zimbabwe), alternative uses for crop residues are difficult to consider; however, kraal manure is often very poor in quality by the time it is applied to crops; alley-cropping research by ILCA and others may lead to more efficient cycling of nutrients between the crop and livestock components, with benefits for both.
- by composting: blending with complementary materials can promote microbial activity and conserve nutrients, but is labour intensive. Composting is discussed in Part 5.

5. Composts

Composting is a biological process whereby a mixed microbial population converts heterogeneous organic matter into a stable, humus-like product useful as a soil conditioner and fertilizer. Biological aspects have been summarised by Borowski and Liebhardt (1983). The origin of the practice seems to have been the need for an easily handled fertilizer in situations where animal manure was not readily available.

a) Benefits

Animal manure allowed to rot in the open loses at least 50 percent of N by leaching and to the atmosphere as ammonia. Labour constraints usually prevent incorporation of fresh manure into soil, which can greatly reduce these losses, although "folding" a portable animal enclosure across a field shortly before ploughing is a traditional low-labour technique used in the western highlands of Ethiopia.

Adding to the manure readily decomposable but low-N wastes, such as crop residues, in a moist aerated stack conserves N and utilizes more of the residues. Some organic soil, partially decomposed manure or previously composted material is usually layered into the stack as a source of microorganisms. Incorporation of the finished compost provides a relatively stable source of OM, where much of the material is already decomposed; incorporation is easier than with fresh residues.

There have been very few reports of field trials of composts in Africa. In the Ivory Coast compost incorporated in a low-N soil at the rate of 10 t per ha produced an immediate yield response from maize; on fertile (N-rich) soil a considerable yield improvement also occurred, but only after a 4-year lag period. This delayed effect is likely to be linked with the long-term improvement seen in soil microorganism activity of organically-farmed soils in the USA, where this occurs despite the lack of effect of organic versus inorganic manuring upon total soil OM levels.

b) Occurrence in Africa

A traditional but crude form of composting consists of allowing manure, bedding and fodder remains to accumulate in the semi-permanent enclosures of zero-grazed livestock, as in high-density areas of northern Tanzania (Kasembe et al, 1983). In the most densely populated areas of northern Rwanda, household refuse is routinely composted in stacks or pits. Very large amounts of compost (e.g 1200 t) were made on large coffee farms in Kenya before the advent of inorganic fertilizers (Wolryche-Whitmore, 1938). Approximately 10,000 t of compost were made in 1950 in the Muranga area of Kenya by small farmers, schools and at local markets (Rimington, 1951).

c) Research results from Africa

There was considerable applied experimentation, both informal and formal, with composting methods and materials in East and Southern Africa between 1925 and 1945, and advances were reported in a series of articles in the <u>East African Agricultural Journal</u> .

One line of investigation focussed on the compostability and performance of waste products from coffee dehulling, cotton ginning, sisal extraction, local markets, etc. Although no overall assessment is provided in the literature, clearly large amounts of compost were produced in large "factories" and some was sold regularly to small farmers. Locally available materials for on-farm composting were sometimes too low in N; for example, the weedy grass <u>Imperata cylindrica</u> in Serere, Uganda produced a very poor compost with little humus formation (Stephens, 1937). Production of Napier grass specifically for composting could be economic on commercial forms but was not always considered to be so on small-scale farms (Stephens, 1937). Nowadays it is accepted that legumes need to be composted to provide N where manure is not available (Ngeze et al, 1983). A survey by FAO in 1979 which elicited responses from 57 countries suggested that few were able to provide information on amounts and kinds of organic wastes and residues that might have potential for increasing compost or mulch production ( ).

A related line of research was on composting techniques. Various modifications were developed on the Indore technique from India (Beckley, 1937), particularly in order to simplify the process and to reduce or eliminate the need for carrying water. Either rain was allowed to wet the substrate before composting, or it was composted fresh before wilting (Tofte, 1937). Addition of roughly mashed leaves of the introduced spineless variety of <u>Opuntia</u> cactus was also said to be promising, due to a water content of 80 percent.

Further requirements for labour were reduced by composting in an above-ground stack rather than in a pit (Rimington, 1951) and by the introduction of ox carts for hauling the finished product. These objectives may be incompatible where pits are needed to conserve moisture.

Most authors at this time agreed on the need for 3-4 turnings of the heap during a composting period of 3 months. Total labour requirements were found to be 10 mandays and 3.5 oxdays per tonne.

More recently, the topics has been researched in more detailed by IRAT scientists in West Africa, as reviewed by Gigou et al (1985). They found that the normal, aerobic methods with millet straw and manure involved a 25-50 percent loss in N during the initial two months, but that N-fixing microorganisms subsequently returned the N content to around its initial level. A longer composting period, of 6 months (more if unchopped straw is used) is therefore necessary.

These authors also reported work in Senegal on anaerobic composting where methane (biogas) production was needed. The cereal straw component appeared little modified during this composting, and although laboratory tests showed the expected immobilization of N by the large amounts of straw, this was not a problem in field trials.

Some recent work, notably in Canada (Mathur et al, 1987) and now proposed in Burundi (Niyondezo, 1987), has examined composting as a techinque for rendering rock phosphates into a more utilizable form. Peat has been proven as an effective acidulating agent for co-composting, but may not be necessary: decomposing OM from manure in normal composting can apparently achieve similar results.

6. Research Needs for Africa

As Swift (1988) has commented, agriculturalists rarely study soil biological processes, due to the success of high input farming that has relied upon fertilizers, pesticides and tractors rather than upon soil processes. Agricultural research in Africa, and more particularly that concerned with small farmers', productivity, has received most attention after the advent of the high-input era. A search of 50 years of the East Africa Agriculture and Forestry Journal from 1935 revealed many papers on composting techniques prior to 1951, and none subsequently. Concern with the processes of accumulation and decomposition of soil organic matter was also concentrated in the first half of this period. We have a much better knowledge of the fate of N fertilizers, and incidently on the quantificaion of BNF, than we have of N losses to the atmosphere.

Within Africa, we have a better understanding of soil processes and their improvement in humid lowlands, on account of the research programs of IITA and others in West Africa, than we have for bean growing areas.

Some suggestions for the future, with particular reference to bean production, include:

1. Nitrogen and phosporus balance studies in major cropping systems of Eastern and Southern Africa, concentrating particularly upon determining (and then limiting) the nature and extent of losses. Greater precision in measurement techniques may be needed for understanding crop implications, since a measured difference of 0.01% N in a lab sample represents 25 kg

N per ha to a soil depth of 20 cm ! These studies should form part of integrated research programs to improve cereal-legume systems.

2. In view of the difficulty of maintaining OM, improving its utilization may be a more productive approach.

3. Verification with farmers of management techniques for kraal or boma manure that reduce nutrient losses without unacceptable labour requirements.

4. Surveys of local sources of OM potentially for composting, and identification of complementary materials for co-composting.

5. Evaluate different legumes and non-leguminous plants for green manuring and mulching under different agroecological zones of Africa for adaptation, biomass production, nitrogen accumulation and fixation, decomposition, etc.

6. Determining under local conditions the effect of a range of OM sources as green manure, mulch and compost on soil properties, nutrient availability, water retention, erosion control, plant protection, including also residual effects & assessing socio-economic acceptability.

7. Develop an ability to predict, for given sets of local conditions, how long surface-applied mulches will last.

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