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Organic matter efficiency

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Introduction

What is efficiency of organic matter, for which role?

The roles of organic matter

Organic matter (OM) in the soils provides different benefits to agriculture or man and can be managed for one or several of these benefits:

- by contributing to favourable soil physical properties, such as resistance to compaction and erosion, high porosity and water-holding capacity, or as a mulch to reduce evaporation;
- as a resource and medium for beneficial soils organisms;
- as a sequestration of CO_2 up to a certain point, therefore reducing climate change;
- as a source or reserve of nutrients N and P for the crops, or as a matter that retains nutrients such as K or, in acidic soils, Ca and Mg and affects the availability of micro-nutrients/-pollutants.

Exogenous OM (added to soil) or endogenous OM (or SOM)?

A certain lexical confusion exists when referring to OM in soil, as in general we use the same term to indicate the OM added to soil or the OM content of the soil (SOM), which is one of the peculiar criteria for pedological classification.

The addition of organic matter in soil as amendment or fertiliser, depending on OM composition and nutrient content, is part of agronomic management due to several benefits provided, as listed above. OM addition may also contribute to maintain or increase organic carbon content in soil, depending on its fate and turnover time. In particular, OM turnover in soil changes dramatically the molecular structure of the OM added producing a new network in which the binding with mineral components determines in large part processes of OM stabilization in soil. Depending on the degree of transformation of the OM added to a soil, at a certain time there are virtually more organic components superimposed: the OM added, the

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fraction partially decomposed and the transformed fraction, the so-called humified organic matter. Measures of soil organic matter (SOM) take into account all these forms together, as detected C contents do not distinguish between organic C « in soil » or organic C «of soil ».

Examples agricultural management to increase SOM in the Mediterranean.

The objective to maintain or increase SOM is also contained among the standards of Good Agricultural and Environmental Conditions (GAECs) established for Cross Compliance implementation under EC Regulation 1782/2003.

Within the issue of protection of soil from erosion, the main practices retained are:

- limiting the presence of bare soils, i.e. guaranteeing permanent organic soil cover,
- reducing soil depth tillage and tillage to a minimum,
- prohibiting some farming practices on sloppy areas, or even
- limiting livestock densities:

all these are connected to the maintenance of SOM.

In the special issue of Italian Journal of Agronomy 2011; 6(s1), experimental results in Mediterranean soils are reported about the effectiveness of crop rotations in maintaining organic matter levels in soils (Borrelli et al., 2011), and the effectiveness of management of stubble and crop residues in the maintenance of adequate contents of soil organic carbon (Ventrella et al., 2011). Results showed that crop rotation could guarantee the maintenance of SOM level, given that the input of C to the soil is maintained at a good level or, in other word, that productivity of the system is high, however it might also depends on the crops of the rotation. Other practices such as conservation tillage, appropriate management of residues, and manure application could enhance the positive effect of rotations. Moreover, preliminary investigation of soil microbial diversity, suggested the positive effect of rotations on soil biological fertility.

The comparison among the effects of burning, the simple incorporation of stubble and crop residues and incorporation carried out with some agronomical techniques (such as the distribution of increasing amounts of nitrogen on crop residue before incorporation) and the simulation of rain (50 mm) on the decomposition of organic material showed that after 32 years of experimentation the simple incorporation of straw and stubble promoted a slight increase in organic soil matter of 0.7% with respect to burning (Ventrella et al., 2011). In that particular pedoclimatic environment, the best results for soil organic

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carbon and soil quality were obtained when residue incorporation included a treatment with additional mineral nitrogen. Conversely, several studies of corn stover shows that N addition to corn stover does not increase the stover decomposition, in case if the ratio does not reach the optimal levels for the decomposition. The reason could be the very tight C:N ratio, especially if it is below the suggested C:N=12:1 value.

Efficiency defined in two questions.

We define efficiency on the base of two questions:

- *Depending on the roles of organic matter which are targeted, what are the required quality or properties of OM to best reach this target?*

And, because organic matter is degraded in the soil, the longer it will last, the more organic carbon you will get from each yearly input. So the second question is:

- *When organic matter is applied or produced in the field: how much will remain in the soil on the long term. In other words, what will be its residence time?*

We therefore summarize:

1) Efficiency of present SOM = quality for a given role
2) Efficiency of applied OM = quality for a given role multiplied by residence time.

The localization of OM (to bring OM where and when it is needed) is also a component of efficiency. From the economic point of view, the efficiency has to be related to the cost of additional OM.

Quantitative fate of organic matter:

How much will remain in the soil on the long term?

After entering the soil, OM is degraded by soil decomposers, mainly fungi and bacteria, and finally is lost as carbon dioxide (CO_2) through the respiration process (we say mineralized). Generally, most of it, the most visible part, is mineralized in less than a few years, but a minority (ten to a few tens of percent) will remain for much longer durations, typically in the Mediterranean it can be for 30 to 60 years in average (Foereid et al. 2011).

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When OM is continuously applied, a mathematic rule relates amount and input of OM on the long-term:

Resulting amount of OM = yearly input$_i$ x mean residence time.

The reasoning is the same as for a population; humans for instance: the size of the population is the rate of birth x the life expectancy.

A strong inequality between soil types and climates.

Two main climatic parameters drive the biological activity and the speed of OM biodegradation: temperature and soil moisture. This is why agriculture is on the average more easily sustainable (less fragile) under the cold temperate climates, which have a higher content of more stable OM, than under the warm tropical ones. All studies and models that have quantified the climate effect consider that the resulting effect at each moment is the product of the temperature effect multiplied by the moisture effect.

Under the Mediterranean climate, the summer drought effects tend to be predominant on the thermic effect by limiting biodegradation. Some models predict that the rate of OM decay varies from a mean annual relative factor 0.7 (slow) in the most arid parts (e.g., mean annual temperature 17°C, annual precipitation 450 mm) to 1.5 (fast) in the coolest (e.g. 12°C, 900 mm).

Concerning the soil, the main driver of SOM residence time is the clay content, which acts through the sorption and the physical protection of OM. Residence time is often considered two times longer in clayey soils (40% clay and above) than in sandy soils. Nutrient availability, pH or $CaCO_3$ content seem to be second order drivers of biodegradation rates in most Mediterranean soils. Specific ecological interactions between organisms (plants, fauna, fungi and bacteria) are presently suspected to mitigate organic matter decay rates at least as strongly as chemical parameters.

The adverse impact of irrigation

As soon as the soil is kept moist during the summer by irrigation, summer biodegradation becomes very active. In the previous case, the relative factor 0.7 can become superior to 2.0 (e.g., in the case 17°C, 450 mm precipitation + 900 mm spring and summer irrigation). Considering only soil organic matter, irrigation therefore increases both carbon input (through increased plant production and returns) and carbon decay (though increased microbial activity). If the total balance tends to be in favour of irrigation, we see here that there is a great potential of innovation in managing irrigation in an "OM-friendly" way, e.g. by decoupling the timing or the localization of OM and root-zone water.

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In-the-soil-produced organic matter lasts longer

In situ root-derived and microbe-derived carbon build more soil organic matter than ligno-cellulosic plant shoot material. For instance an ancient isotopic study in Denmark revealed that, when the input of glucose is compared to that of wheat straw, there remains more carbon after 10 years in the case of glucose! It is an apparent paradox because glucose decays in a few hours and straw in a few years. One explanation is that sugars and easily degradable substrates are converted with a high yield into microbial biomass (30-40%). Additionally the soluble matter is introduced directly inside the soil particle matrix and the microbial products formed there, which are rich in polysaccharides and proteins, tend to be adsorbed. The process is in probable interaction with the clay minerals of the soil, which protect these products. On the other hand almost all the studies that tried to quantify the fate of carbon derived from the rooting systems (the belowground restitution from crops) concluded that, at equivalent biomasses measured at harvest, roots contribute more than aerial parts to SOM on the long term. (1.4 to 2.3 times more depending on the studies). The same processes than the one involving microbes, through fine-root turnover and exudation can be invoked.

This fact has some consequences. The efficiency of easily degradable materials should not be underestimated. Because increased primary production is a major source of OM, exogenous OM can contribute to soil organic matter also through the increase in plant production it promotes, in a virtuous circle. In the domain of varietal innovation, cultivars with high root production should be considered for OM improvement, but, unfortunately, plant breeding does not usually take this character in consideration for itself, and furthermore often develops cultivars under optimal water and nutrient supply, which are conditions that counter-select efficient rooting system. In Hungary, which is known as one of the most sensitive country in Central Europe of the Global Change, few maize varieties were selected on the basis of their rooting volume and depth; and those selected ones become better survivor of the strict summer drought (Dusha, personal comment).

Soil Organic matter quality

Qualit<u>ies</u> for the different roles (physical, nutrient, chemical, biological)

There are different types of molecules in soil organic matter. We classify them in three groups:

- fiber-derived material, e.g. ligno-cellulosic remains,
- lipids, microbial polysaccharides, proteins and so called

- humic compounds, which are aggregates of small molecules naturally derived from the former.

The first type is poorly efficient for physical properties (except for mulching). On the contrary, the two others are more efficient, because these molecules are flexible and can stick mineral surfaces. Considering the chemical fertility, these two groups are also the most efficient because fibers are nutrient poor and have a low sorption capacity.

As a result, easily degradable material and microbially processed matter, such as composts and sludges, are generally more efficient than barks, chipwoods or straws for most of the functions of organic matter.

Keep or degrade organic matter? The dilemma.

Considering the delivery of nutrients to plants, of course the more nutrient OM contains (mainly N and P), the more efficient it is. But the question of efficiency is more complex because there is a dilemma: decomposition of OM, which delivers the nutrients, is also the destruction of organic matter. A rapid liberation of N to the crops (as in the case of slurry), can be difficult to manage because of the risk of leaching into groundwater, especially in winter. On the contrary a higher reserve of less available nutrients in organic forms is more efficiently used by plants, especially by perennial crops, which are helped by fungi to get these nutrients when they need them. Organic phosphorus is also more efficient than inorganic phosphorus, especially in Mediterranean red, iron-rich soils where the latter is strongly sorbed. As a summary, OM with high N and P content and with a slow decay rate can often be preferred.

Localize OM where it is needed

For physical properties, organic matter efficiency increases together with its concentration in soil. This is the reason why inversion tillage (by mouldboard plough), by diluting organic matter with more mineral matter, leads to low OM contents at the surface; and the deeper the tillage, the higher the dilution. When the properties of the topmost part of the soil are critical (i.e., for erosion risk, crusting risk, or enhanced earthworm activity), reduced tillage increases automatically and concomitant the efficiency of OM. But it has to be never interrupted by an inversion tillage, which would cancel the benefit immediately.

Assessing efficiency of OM sources

Ranking OM sources

Long term experiments have compared the quantitative fate of most frequent sources of organic matter.

Indices of humification, such as the Index of Biochemical Stability (Linères and Djakovitch, 1993), and the Humus Stability Coefficient (Hargitai, 1993) are estimates of the quantity of organic carbon remaining on the long term, expressed as a proportion of the initial carbon. Out of some very resistant products such as peat and barks, these indices currently range from 10 to 30% and are lowest for straws and higher for manure, composts and sludges.

How to classify high C-bearing materials?

A different consideration should be put into another class of materials that are not properly « OM », although they are derived from the agro-industrial chain. Much attention has been paid in last years to pyrolized products, such as biochars, due to their high both C content and stability against decomposition in soil. The offset of climate change by the agro-waste biochar products is also known (Stavi and Lai, 2013). There characteristics should be favourable to C enrichment in soil. However, chemical-physical characteristics of such products are dramatically different from fresh or composted biomasses, as the network of OM functional groups is destroyed by high temperature pyrolysis and so their resulting composition (as instance high C/H ratio) is more similar to fossil carbon. They present interesting properties for amendment use, such as high surface area, which is known to provide shelter, oxygen, water and protecting surface for the microorganisms. Such "carbon" materials are suggested as efficient substrates therefore to the potential remediation of highly contaminated soils (Libisch et al. 2012). The efficiency of biochar addition to soil should be high when considering the high residence time (efficiency definition 2) or low when considering the effective capacity to enter into C turnover in soil (efficiency definition 3).

More discussion is needed about the effective role of these materials in increasing the content «of» SOM (i.e. the Soil Organic Matter) rather than the content of Organic Carbon «in» soil.

Composts qualities

Many available products are composted before being applied to the soil. This addresses the need to apply stabilized OM onto the soil and to avoid leaching of compounds which are phytotoxic for seedling and root development. As the biodegradation progresses during the composting process, the remaining matter progressively becomes more resistant to biodegradation and will therefore have a higher soil organic matter yield after being applied. This leads to very variable properties of composts depending on the "degree" of composting and the composition of raw materials. It would make sense to compare the fate of the material on the basis of the initial quantity of carbon. Many methods, both chemical-physical and biological, are currently available to assess compost stability. However, a basic characteristic of composts would be very useful: the ratio residual/initial carbon of the compost (the ratio is perfectly known by the composting companies, because linked to the input-output balance) and it depends, among different factors, also from raw materials characteristics. OM from different sources is generally distinguished by

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few basic parameters, such as C and N content, etc. However, OM composition is more complex from different points of view, including the microbial consortium associated to the specific OM sources which are loaded into the composting plant. This implies the possibility that microbial decomposition occurring during composting process could follow different biochemical pathways depending on the microbial loading associated with the different raw materials. This was shown in composts differing for OM source composition (Klammer et al., 2008 ; Dell'Abate and Tittarelli, 2002).

Conclusions

- The input of organic matter, by generally increasing plant production and therefore plant carbon restitution to the soil, increases soil organic carbon in a virtuous loop.

- There is a potential of innovation in the Mediterranean by managing irrigation in an "OM-friendly" way, e.g. by decoupling the timing or the localization of OM and root-zone water.

- The content of applied OM in organic nitrogen (not total nitrogen) is a good indicator for both OM quality and OM effect on the long term.

- Concerning composts, the ratio residual/initial carbon of the composting process (which is perfectly known by the composting companies, because linked to the input-output balance) would be a meaningful and costless additional indicator of compost quality.

- A decision tree for organic matter application should take first into account for the services that are targeted.

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