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Key soil functional properties affected by soil organic matter – evidence from published literature

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Abstract. The effect of varying the amount of soil organic matter on a range of individual soil properties was investigated using a literature search of published information largely from Australia, but also included relevant information from overseas. Based on published pedotransfer functions, soil organic matter was shown to increase plant available water by 2 to 3 mm per 10 cm for each 1% increase in soil organic carbon, with the largest increases being associated with sandy soils. Aggregate stability increased with increasing soil organic carbon, with aggregate stability decreasing rapidly when soil organic carbon fell below 1.2 to 1.5 %. Soil compactibility, friability and soil erodibility were favourably improved by increasing the levels of soil organic carbon. Nutrient cycling was a major function of soil organic matter. Substantial amounts of N, P and S become available to plants when the soil organic matter is mineralised. Soil organic matter also provides a food source for the microorganisms involved in the nutrient cycling of N, P, S and K. In soils with lower clay contents, and less active clays such as kaolinites, soil organic matter can supply a significant amount of the cation exchange capacity and buffering capacity against acidification. Soil organic matter can have a cation exchange capacity of 172 to 297 cmol(+)/kg. As the cation exchange capacity of soil organic matter varies with pH, the effectiveness of soil organic matter to contribute to cation exchange capacity below pH 5.5 is often minimal. Overall soil organic matter has the potential to affect a range of functional soil properties.

1. Introduction

Much of the recent interest in soil organic matter has been as a vehicle to increase soil carbon levels in order to trade carbon or to gain benefits in market based instruments for carbon. However, it can be argued that the potential effects of soil organic matter on the productive capacity of soils are also of practical and economic importance and of significant interest to many in the agricultural community. It is the objective of this review, to concentrate on the capacity of soil organic matter to be an agent to maintain and improve soil condition and soil health and so the productive capacity of the soil.

While several reviews have been undertaken and suggest it is difficult to find quantitative evidence that soil organic matter improves soil properties [1], the approach taken here has been to investigate more directly the effects of soil organic matter on individual soil properties, especially through any pedotransfer functions that relate soil organic matter to the values of individual soil properties. It is clear that soil organic matter affects a range of soil properties and therefore any assessment of the influence of soil organic matter on productivity needs to consider this broad range of effects. In a final



conclusion a paper that evaluates the overall effect of soil organic matter on overall productivity is reviewed. The detailed review is presented in [2].

2. Soil organic matter and functional soil properties

A summary of the effects of soil organic matter on some of the major functional soil properties based on the review is given below. The summary is based on an evaluation of the published information and pedotransfer functions and relationships relating the soil properties to soil organic matter levels.

2.1. Water holding capacity

A range of pedotransfer functions that included soil organic matter as one of the variables were evaluated [3], [4]. Several features of the relationship between soil organic matter and soil water holding capacity became evident.

- As a general guide the plant available water between 10kPa and 1500kPa increased more for sandy soils with increasing soil organic carbon than for clayey soils. The general trend is shown below but this is only a very general guide, with more detailed data required for making specific recommendations:
 - Sandy soils by about 3 mm/100mm of soil for every increase of 1% soil organic carbon
 - Loam soils about 2.5 mm/100mm of soil for every increase of 1% soil organic carbon
 - Clayey soils about 2 mm/100 mm for every increase of 1% soil organic carbon.
- The amount of water held at 10 kPa and at 1500 kPa increased with increasing soil organic matter although the amount of water held at 10kPa increased at a greater rate.
- The increases in soil organic matter tend to be limited to the surface soils and probably the top 5 to 10 cm. This limits the capacity of increases in soil organic matter to increase the overall water holding capacity of a soil profile.
- The changes in water holding capacity associated with increasing soil organic matter are complicated by the effects of soil organic matter on bulk density.
- The predictions of the effects of soil organic matter on water holding capacity varied within the published literature and this is a reflection of the different data set and soils used to derive the different pedotransfer functions.

2.2. Aggregate stability

While not a functional property itself, aggregate stability is a fundamental physical property of the soil that influences many other soil physical properties. Good aggregate stability is generally considered to be required to maintain good soil structure and a suitable soil physical condition of the soil for plant growth, infiltration and control of erosion. In general a level of soil organic carbon of 2 to 2.5% is considered necessary to maintain good aggregate stability [5] and aggregate stability is considered to deteriorate rapidly when SOC falls below 1.2 to 1.5% [5]. The relative importance of soil organic matter in maintaining aggregate stability varies with texture. In sandy soils soil organic matter is the most important factor, in clayey soils cation balance can be the most important effect and in loamy soils both cation balance and soil organic matter are important [6].

2.3. Compaction characteristics and friability

Several published relationships showed that the compaction characteristics of soils, friability and the Atterberg Limits (strong indicators of the compaction and tillage characteristics of soils) are all strongly affected by soil organic matter and from an agricultural and cropping viewpoint are improved by increasing soil organic matter [7]. In general, When the soil organic carbon % falls below 1%, the compaction and friability characteristics of soils became more limiting for plant growth and tillage operations[8,9], but this requires further investigation. Again texture is important with more clayey soils less influenced by soil organic matter [7].

2.4. Soil erodibility

Soil erodibility is only one factor in determining the potential for water erosion with rainfall erosivity, length and degree of slope and land management factors such as cover and the presence of loosely tilled soil being other factors. However it when soil organic matter falls below 2% (SOC < 1.2%) soil erodibility is considered to increase [10]. Good aggregate stability in reducing erosion and so this is related to soil organic matter and especially the amount of aggregates > 125 μ [11].

2.5. Nutrient Cycling

A major feature of soil organic matter is that it holds a relatively constant ratio of the different nutrients [12]. For every 1 tonne of soil organic carbon there is 83 kg of N, 20 kg of P and 14 kg of S [13]. This does vary between soils and with history of crops, pastures and land management, for example the amounts suggested by Williams and Donald [14] for long term pastures are 65 kg of N, 4.4 kg of P and 9 kg of S. In the decomposition of the soil organic matter these nutrients can be released into the soil although how much becomes available to plants depends on a range of factors. In the formation and then in the decomposition of soil organic matter, a flux of nutrients or a recycling of nutrients is an outcome. Thus soil organic matter can be an important sink and source of nutrients in agricultural production.

Nitrogen is a dynamic nutrient being continuously recycled between the atmosphere, the soil solution, soil organic matter, plant material and soil organisms. Soil organisms are responsible for the transformation of nitrogen between these different pools. Mineralisation of soil organic matter by which nitrogen in soil organisms, plant material and soil organic matter is converted to mineral N (nitrate and ammonium ions) and made available to plants is a major process for the provision of N. Effectiveness of mineralisation depends on the chemical characteristics of the substrate material particularly its C:N ratio and its lignin content. Substrates with high C:N ratios (generally cereals) are likely to result in N being fixed in the soil organism pool and becoming unavailable to plants. While the mineralisation of soil organic matter under aerobic conditions results in the formation of nitrate and ammonium ions, under anaerobic conditions the gases N₂O and N₂ can be formed rather than mineral N.

Phosphorus occurs in several pools in the soil and in many soils the P from soil organic matter may be only one of these pools (Shen et al.)[15]. It estimated that P from soil organic matter is generally about 40% of total P in the soil, but this can vary from 20% to 80% depending on the soil type. Soil organic matter can prevent P being fixed into unavailable forms by the Fe and Al minerals [16] keeping it in a form which remains in the available pool for plants, even if this organic P needs to be mineralised before it becomes immediately available to plants. The mineralisation of plants and soil organic matter can be a major source of P for plants [17].

Sulfur is predominately supplied from the soil organic matter in most soils although some soils have a high mineral level of S such as those high in gypsum and some volcanic soils and some soils associated with marine deposits having been associated with acid sulphate soils.

The soil microbial population can be a critical factor in the effectiveness of nutrient cycling through soil organic matter. Maintaining soil biological health is an important factor in the functioning of soil organic matter [18]. Land management can influence the microbial populations in soils and their effectiveness in nutrient cycling to maximise the amount of nutrients that become available to plants [18], [19].

2.6. Cation exchange capacity

It is clear from the published information that soil organic matter can have an effect on cation exchange capacity but it is complex as it is dependent on the texture of the soil, but also on the pH range of the soil [20]. Much of the soil organic matter fraction that contributes to the cation exchange capacity has variable charge and this is why the effect of soil organic matter on CEC is pH dependent. Below pH 5.5, it appears that soil organic matter does not contribute greatly to CEC. The relationships between soil organic matter and CEC were shown for sets of well-defined soils [21], [22]

but the relationships were different for the different soil groups. For a chernozem group of soils the CEC of the soil organic matter was 297 cmol(+)/kg and 134 for a group of acid soils [21]. In red earths, it was estimated the soil organic matter had a CEC of 172 cmol(+)/kg [22]. It would appear that most of the charge contributing to the CEC is from the humus fraction.

2.7. Buffering capacity to acidification

The capacity of soil organic matter to buffer the soil against soil acidification has been recognised in both Queensland and NSW [23], [24]. Its capacity to buffer against acidification is also dependent on texture and clay content. While increasing the soil organic matter can increase the buffering capacity against soil acidification (possibly up to 3 tonnes of calcium carbonate by increasing soil carbon by 1 to 2%), in general this will only provide short term slowing of acidification as the acidification rates will generally be sufficient to overcome the increased buffering by higher soil organic matter levels, up to 10 to 15 years based on Fenton and Helyar [25]. However, this increased buffering capacity may provide short term agronomic and economic benefits in some soils.

3. Assessing the overall impact of soil organic matter on functional soil properties

Soil organic matter can affect a wide range of soil physical and chemical properties. It can affect the nutrient cycling and nutrient availability in soils. Predicting the overall impact of soil organic matter on productivity is complex because of the wide range of potential effects of soil organic matter. The effects are also likely to be dependent on seasonal conditions and soil type, especially soil texture. Indications are that once soil organic carbon levels fall below 1%, then a wide range of soil properties can be adversely affected. Given the complexity of the potential effects of soil organic matter on soil functions, the use of biophysical models such as ASRIS, is suggested as a useful method to examine the overall effects of soil organic matter on productivity in more detail.

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