GLOBAL IMPLICATIONS OF SOIL ORGANIC MATTER

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Abstract

The suggestion that sequestering carbon in soil organic matter creates a financial cost through the need to replace co-sequestered nutrients is examined. The natural supply of nutrients to vegetation is elucidated and the impacts of land use practices such as fertiliser application are outlined. The global warming implications of these impacts on soil organic matter and the development of vegetation are discussed.

Introduction

The observed increase in atmospheric CO_2 is commensurate with the loss of carbon from soils associated with conversion of land from native vegetation to agriculture. Soils almost invariably loose carbon when converted to agriculture due to the increased rate of breakdown and decreased rate of production of organic matter by microbes, particularly the long lived forms of organic matter such as humic compounds.

The breakdown of soil organic matter (soil OM) occurs via biological combustion wherein the carbon is released as CO_2. The breakdown is accelerated by management practices such as tillage and the application of mineral fertilisers. Over the last century the increase in atmospheric CO_2 is commensurate with the loss of soil organic matter. If global warming is due to increased levels of atmospheric CO_2 then it can be effectively addressed solely by adopting land management practices that rebuild the levels of soil organic matter.

Despite the potential for addressing levels of atmospheric CO_2 by building soil OM it has been given low priority. Indeed, some public scientists even suggest that it could be counter productive because soil organic matter makes nutrients unavailable to plants (GRDC Southern Panel 2008). This binding of nutrients, which represents nutrient sequestration, is taken to represent a monetary cost related to the fertiliser needed to replace them.

Addressing carbon sequestration through soil OM is considered non viable because the cost of 'replacing' the sequestered nutrients using fertiliser is identified as being potentially greater than returns from carbon credits arising from the soil OM. This conclusion is reinforced where the carbon cost of producing and applying the fertiliser are considered.

With this approach the desirability of increasing soil OM is assessed solely by way of potential monetary return from carbon credits. However, the monetary returns from increasing soil OM go well beyond any return from carbon credits as farm profitability within a region has been positively correlated with the levels of soil OM. Moreover, soil OM has indirect benefits to the environment and plant and animal health that are of much greater consequence than an immediate monetary return. The assessment is being made on a single factor in carbon sequestration wherein the sequestered carbon has an artificial value as no one can reliably demonstrate that its sequestration can achieve the desired effect.

Attempts to evaluate the value of soil OM in such a simplistic manner are absurd, particularly when carbon sequestration represents an economic solution to an environmental problem. Other issues include whether significant amounts of nutrients are sequestered in soil OM, and whether fertiliser is needed to ‘replace’ nutrients in soil OM to maintain crop yields.

Attempts at obtaining an explicit explanation as to what nutrients are regarded as being sequestered in soil OM were unsuccessful. They served only to elicit questions as to what was meant (the question was met with a question) together with the provision of some ‘information’ on the complexities of the composition of soil OM.

Logically the suggested sequestered nutrients should be elements associated with long lived organic matter, essentially humic acids. As nitrogen, potassium and phosphorus (NPK) are the main nutrients applied in fertiliser the calculations would effectively depend on the levels of these elements.

This paper first addresses the sequestration of nutrients in soil organic matter and the implications of the proposition that nutrients bound to soil OM must be replaced using mineral fertiliser. The significance of soil OM for global warming is discussed.

Basis of the Proposition of Nutrient Sequestration by Soil OM

The suggestion that soil OM makes nutrients unavailable to plants is contrary to the general consensus that derives from a large and diverse array of studies on crop growth and yields. Fertility, and hence crop and pasture growth, is generally positively correlated with soil OM. Situations arise where the addition of organic matter to soils can temporarily reduce nutrient availability to plants but the duration of the effect is short, and the effect is not associated with the long lived forms of soil OM involved in carbon sequestration.

There is no known theoretical or empirical basis for the conclusion that nutrients in long lived soil OM must be replaced using fertiliser. The conclusion appears to derive from the application of a simple budget under the assumption that all nutrients used by plants derive from added fertiliser. With this assumption all nutrients lost from the system by whatever means must be replaced using fertiliser. However, in natural systems all of the nitrogen comes from the atmosphere, which is the same as for the carbon in soil OM.

Carbon and oxygen comprise the bulk of soil OM by weight, carbon almost half and oxygen a little over one third. The carbon indirectly derives from atmosphere through fixation of CO_2 by plants. The oxygen derives directly from the atmosphere as a gas, or indirectly through the dissociation of CO_2 and H_2O.

Hydrogen and nitrogen are the next major constituents of soil OM, and comprise around 10% by weight in long lived forms. They occur in roughly equal proportions by weight.

The hydrogen and nitrogen derive from the atmosphere, as with the carbon and oxygen. 98% of the nitrogen derives indirectly through fixation of atmospheric nitrogen by microbes, with around 2% being attributed to lightening causing the gas to go into aqueous solution. The hydrogen drives through the dissociation of water.

A range of other elements can occur in the backbone of humic compounds but the amounts are low compared to the four main constituents. These elements derive from soil minerals and their composition in the soil OM reflects the soil mineralogy.

With natural systems little of the weight of organic matter derives from the mineral soil, be it in plants or the soil. This was demonstrated for plants before the existence of elements and gases was known. There need be no reliance on fertiliser when sequestering carbon in soil OM. Even if nutrients sequestered in soil OM are derived from fertiliser the only nutrient that can be sequestered to any significant extent is nitrogen.

The above considers the elements associated with the backbone of humic compounds where these constitute only some of the elements determined in a chemical analysis of soil humus. Humus is a very strong chelating agent and numerous elements can be chelated (adsorbed) to sites on the complex molecules, particularly bivalent cations. These chelated elements are readily available to plants through ion exchange thus only elements forming the backbone of humic compounds can be sequestered.

The high chelating capacity of humic compounds, and other forms of soil organic matter, is a prime reason for the positive correlation between soil OM and fertility. Plants require a supply of nutrients throughout their growth hence the soil must act as a nutrient reservoir. Most soluble nutrients would be lost through leaching without an effective storage system where soluble nutrients are most readily available to plants. Soil OM provides the necessary storage and hence maintains a supply of nutrients throughout the growth of a plant. In doing so it greatly reduces the loss of nutrients from the soil / plant system.

The other main reason for the positive correlation between soil OM and plant growth relates to the effect of the soil OM on soil structure. Different forms of microbially produced organic matter interact with soil minerals to improve soil structure. The percentage gains are greatest with sands but the improvements are great regardless of whether the soils are predominantly clay or sand. The exact level of benefit from the interaction cannot be reliably given because soil OM directly has the same effects as arise from the interaction, but the benefit of the interaction is several times greater than the direct effect. Soil OM provides much greater benefit when mixed with mineral soil than when on its own.

The effects of the interaction between soil OM and minerals go well beyond nutrient storage and include aeration and water storage. Appropriate levels of soil OM greatly increase the ability of the soil to store water in the range of potentials available to plants: soils act as a reservoir for water in the same way as for nutrients. Moreover, the improvement in soil aeration greatly improves plant access to stored water and nutrients, and the ready availability of oxygen promotes the physiological functioning of roots and hence their growth.

An optimum level of soil OM cannot be precisely given but 2% by weight is generally regarded as the minimum desirable. Maximum benefit usually occurs at around 4%, while increasing the level above 8% can be detrimental. Achieving the best outcome requires the mineral soil and organic matter be in specific proportions but the optimum proportions vary with the soil mineralogy and the form of the organic matter.

Soil OM is highly beneficial in promoting plant growth and therefore crop yields. Increasing the amount of organic matter in agricultural soils from their current levels would provide large financial gains as well as benefiting the environment and health. Moreover, no significant amounts of sequestered nutrients need derive from added fertiliser. There is therefore a need to assess how the conclusion arose that sequestration of carbon in soil OM represents a monetary cost in terms of sequestered nutrients.

The notion that soil OM sequesters nutrients that must be replaced using fertiliser could have derived from the simplistic assumption that all nutrients in crops derive from fertiliser. It could also have arisen because of a lack of discrimination between chelated elements and those forming the backbone of the compounds. The C:N ratio of 10 and the costing given in slide 5 of the 2008 GRDC Southern Panel power point identify that both these invalid assumptions were applied. However, slide three of the power point identifies a more fundamental reason. The relevant points in the slide are:

> *Soils differ in their capacity to hold C*
> Nature of soil minerals & CEC
> Composition of soil microbes
> There tends to be a natural equilibrium

This suggests that the soil cation exchange capacity (CEC[1]) affects the accumulation of soil organic matter when the accumulation of soil organic matter has a pronounced effect on the soil CEC. The CEC of the mineral component of soils effectively derives from clay but the CEC of the best clay mineral is much less than that for soil OM. Moreover, the interaction between the soil minerals and organic matter greatly enhances the effective CEC.

CEC is being presented as a control for soil OM when it is an outcome. High CEC arises because of the accumulation of organic matter in soils and the CEC has little if any direct effect on the accumulation of soil OM.

The prime controls on the development and accumulation of soil OM are not given in the GRDC power point, namely water (rainfall), temperature, food/ substrate, and soil aeration. These controls arise because organic matter is formed and broken down by microbes, hence the accumulation is determined by factors that control microbial activity. As the food for microbes is plant residues, the food/substrate factor is in effect fertility by way of nutrient availability to plants.

The conclusion that the accumulation of soil OM deprives plants of nutrients is contrary to reality. However, it is hardly surprising that such a perverse conclusion can be drawn when the identifications of cause and effect are opposite to reality. Given an inability to correctly identify causes (controls) and effects (symptoms / outcomes) there is no chance of obtaining valid conclusions. There has been a fundamental failure in application of the scientific method that is of great consequence given the complexities of the system being addressed and the implications of the conclusions.

Basics of the Soil – Plant Nutrient Balance

Comprehensive plant-soil nutrient budgets don't exist primarily because of the difficulty in measuring the available nutrients. The issues are the forms in which elements are plant available, the means by which non plant available forms can be converted to available forms, and the ability to measure the different forms.

The existing levels of most elements are generally much greater than needed by plants but most are in forms that are unavailable to plants. For example, nitrogen is abundant as a gas but has to be converted to ammonia (NH_4^+) or nitrate (NO_3^-) to be available to plants. As a compound phosphorus is identified as only being directly taken up when in the forms H_2PO_4 and HPO_4.

The levels of nutrients present in soils in plant available forms are generally very low as they are rapidly taken up by plants. The available forms of elements therefore do not provide a reliable indication of soil fertility. The measurements of soil fertility used in practice

[1] CEC is a measure of chelating capacity and hence ability to store nutrients in a form available to plants.

therefore address compounds that can readily be used by microbes which supply the elements in plant available forms.

The other main constraint in establishing nutrient budgets is common to all measurement wherein the results are largely determined by the available technologies. The estimates of nutrient availability are based on various extraction techniques, such as acid or base extractable. The practical use of such measurements is based on empirical observations that compare the estimates of nutrient levels with plant growth. The use of the measurements is based on empirical correlations and only through experience is one method regarded as superior to another. There is currently no single good measure of soil fertility except, perhaps, for soil OM.

Provision of nutrients to plants

Terrestrial vegetative systems have evolved over millions of years as an integrated whole. This evolutionary development has resulted in the more recently evolved forms of organisms being dependent on earlier forms. For example, higher plants depend on bacteria for their essential supply of nitrogen. The bacteria can be free living or in symbiotic relationships with plants.

Plants benefit greatly from the existence of the nitrogen fixing bacteria to the point where plants may not have existed without them. However, whether free living or symbiotic, the bacteria benefit from the development of plants as the organic matter from plants is their main or sole source of food. Development of the nitrogen fixing bacteria depends greatly on the development of plants.

The situation is the same for phosphorus as for nitrogen. Essentially all phosphorus in rock minerals is unavailable to plants but it can be extracted by bacteria. Phosphorus becomes available to plants through bacteria.

The situation with other nutrients is generally not sufficiently well known to provide a clear exposition on the mode of supply. With readily soluble nutrients, such a sodium and calcium, there is no need for such a relationship as the elements are readily available to plants. However, for many other elements the need for a mutualistic association likely arises.

The relationship between plants and microbes is critical for the development of vegetation regardless of how many elements are supplied to plants via microbial activity. The mutualistic relationship with nitrogen alone is sufficient to justify the conclusion that the development of vegetation depends completely on the functioning of bacteria.

The above addresses the provision of nutrients in a plant available form but to obtain benefit plants must have effective access. Free living bacteria are effectively distributed throughout the soil, albeit concentrated in the surface where the provision of food is greatest. However, plants essentially represent point sinks. Plants must therefore have effective collection systems to bring nutrients to their point.

Roots are the plant structures that function as nutrient collection systems in soils. However, even the smallest root is physically large compared with the atomic level at which nutrients are stored (adsorbed / chelated) on clays and organic matter. For effective ion exchange the plant root must be very close to the chelated ion. This size constraint is addressed to a limited extent by the development of root hairs but these are limited by their size, short longevity, and their occurrence being limited to growing root tips.

To improve the effectiveness and efficiency in gaining nutrients plant nutrient collection systems have evolved around mutualistic associations with fungi. Glomalean (arbuscular) fungi in particular have formed symbiotic relationships with plants whereby the fungus lives and reproduces within plant roots but the hyphae extend well out into the soil. These hyphae provide a much more effective and energetically efficient collection system for nutrients than could be provided by plant structures alone.

The symbiotic association between the fungi and plants is mutually beneficial as plants provide food for the fungus and the fungus provides nutrients for the plants. Other benefits likely include the fungi providing defence for plant roots against pathogenic microorganisms.

Microbe investment in long lived organic matter

Organic matter represents the food for a great diversity of microbes yet microbes are expending energy to convert potential food into a reservoir of organic matter that is essentially unavailable to them. Microbes are expending energy to convert organic matter into long lived forms such as humic acids where the longevity of the compounds primarily relates to their resilience to breakdown by microbes.

With evolutionary development such expenditure of energy and lack of direct utilisation of a resource does not occur unless it confers indirect benefits in excess of the potential direct benefits. In this instance the indirect benefits relate to investment in infrastructure that modifies their environment. The interaction between the long lived organic matter and mineral soil greatly increases the permeability of the soil to air and water and so directly greatly increases the available resources by way of minerals and water. Indirectly it also increases the availability of energy to the microbes by promoting the growth of plants.

The beneficial modification of their environment by microbes is much greater than anything achieved by humans. It is also much more effective. Most of the environmental modification by humans provides short term benefits but is highly detrimental in the long term.

Conclusions on the nature of soil

Soil is not simply a physical medium that props up plants and holds applied water and nutrients needed for plant growth. It is a diverse community of organisms that functions through a complex of mutualistic associations, prime ones being between microbes and plants. Vegetation depends on the effective functioning of the living organic component of soils. Destroying any one of the mutualistic associations between soil microorganisms and between plants and the soil organisms reduces the development of vegetation. Damage to any of the associations reduces the productivity of the system.

Changing the Soil Environment

Application of anything to a complex system that functions through interactions alters it in some way. As the system has evolved to some form of optimum the applications will generally degrade the functioning. Applications that are uniform and/or have high concentrations have greatest adverse impact.

The soil-vegetation system has evolved in the same manner as human communities where different sectors perform different functions. Damage to one sector impacts most if not all of the others, and damage to critical sectors can effectively prevent the system from functioning. The system can always recover because the diversity allows the development of ‘work arounds' to compensate for a lost or degraded capacity, but the resulting outcomes are seldom as good as before. While new developments can sometimes be better than the prior situation these are the minority, and they take considerable time to develop. There are never any simple solutions that provide quick fixes.

While soil microbes utilise organic matter from plant residues as food the addition of organic matter need not be beneficial. Organic matter low in nutrients and composed of material resilient to breakdown, such as wood chips, will have little impact other than to the space that it occupies. However, organic matter rich in nutrients and readily decomposable carbon compounds produces a great flush in the growth of some groups of microbes. This growth flush can tie up resources essential for other groups of microbes wherein the imbalance reduces the availability of nutrients to plants.

The situation is equivalent to a species invading new territory, as with rabbits and cane toads in Australia, as there is sudden availability of abundant resources. The invading populations initially flourish and expand to extreme levels to the detriment of others, and to the total system. However, the invaders then crash because of the depletion of resources on which they depend. Several minor peaks in the invader populations usually follow before the system establishes a new quasi static dynamic equilibrium[2].

The commonality with the addition of any form of organic matter is that biological feedbacks return the system to something like its prior functioning. The eventuating system may be more or less productive than existed before but it will be generally similar. The addition of organic matter seldom changes the fundamentals of the system.

Providing an abundance of plant available nutrients to increase plant growth, as with the application of mineral fertilisers, can increase the availability of food for microbes through increased plant production. However, in doing so it makes redundant the mutualistic associations between plants and microbes central to the development of the system. Plants have no need to expend resources on maintaining the microbes that previously supplied the applied nutrients and so the microbes involved in mutualistic associations decline. The investment in infrastructure by such microbes to develop the soil environment therefore declines.

Allied to the decrease in production of long lived soil OM there is an increased rate of breakdown of existing soil OM. The high supply of nutrients promotes the development of microbes that break down the existing organic matter but do not produce resilient forms. The soil structure declines because existing infrastructure is broken down at an increased rate and the rate of development of new infrastructure is diminished. Soils become compacted and are then poorly aerated and hold less water and nutrients. All factors combine to restrict the development of plant roots and reduce plant growth.

Allied with the decline in soil structure there is reduced accession of nutrients by microbes. This reduction applies to accession of new nutrients from soil minerals, the storage of nutrients in the soil, and the transfer of nutrients to plant roots. Damage to microbial populations adversely impacts all aspects of nutrient accession by plants. Development of vegetation then becomes dependent on the continuous application of fertiliser. Once mineral fertilisers have been used the system depends on their continued application.

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[2] The jumble of words indicates that natural systems are never static or stable. They naturally fluctuate and change. They may tend to an optimum but there are many optima. Even if an optimum is attained it cannot be maintained.

Microbes supply all of the more than 60 elements needed by plants in an appropriate form and relative abundance. The elements supplied in mineral fertilisers are only a small subset of these. Indeed, manufactured fertilisers can only ever contain a small subset of the necessary elements. As mineral fertilisers are deficient for plants by way of the elements present they are also deficient in the balance between them. These deficiencies limit the growth of plants and degrade the nutrition of the resulting produce.

A large plant response occurs when first applying mineral fertilisers because the soil structure is good and all of the other essential elements are readily available. However, with ongoing application the plant response from a given level of fertiliser application declines due to the decline in soil structure and the depletion of essential elements other than those applied. This degradation has been addressed by progressively increasing the application fertiliser to achieve the same level of plant response. Additional elements such as copper are applied to address newly developed deficiencies.

A point is eventually reached where crop yields decline regardless of the amount of fertiliser applied. This situation is inevitable because of the need for a diversity of nutrients additional to those applied. Stores of at least some of the more than 60 elements needed by plants become depleted because of the adverse impacts on microbial populations and soil structure. The normal supply chains for the essential elements are effectively broken.

The decline in nutrition of the plants is reflected in reduced nutrition of the produce, and thus the nutrition of consumers. The usual 'solution' applied with food is the same as with soils, that of adding supplements to address identified deficiencies. This is as non viable as relying on mineral fertilisers in soils due to the inability to identify and redress all deficiencies.

The situation with the use of mineral fertilisers in farming is directly analogous to drug addiction. Their use initially produces a high but over time the dose has to be progressively increased to achieve the same effect. Eventually a wall is hit wherein no dose is enough and the returns from the applications do not pay for the habit. The decline in the system throughout this regression commonly results in a premature and painful death.

There is no option of gradually withdrawing from the habit by taking lower doses as the system becomes dependent on the drug/fertiliser to function at any level. The only solution is to drop the drug and change habits. The healthy situation for the soil, vegetation, and consumers of the produce is to return to the naturally evolved system wherein nutrients are supplied to plants via microbes. To be effective any nutrients applied to the soil must therefore be supplied in a form and manner that promotes the development of the soil microbial community.

Beneficial management

Soils can undoubtedly be managed to sustainably improve plant production as it was done thousands of years ago. There are also examples from the last century. Different approaches have been used and each approach contains details that relate to the particular circumstances. There is no single best solution and the management practices vary with the conditions and constraints. There are, however, some generalisations.

The guiding principle is the need to promote the entire soil biological community as promotion of any particular component will be detrimental[3]. Practices such as uniform heavy

[3] The analysis focuses on the supply of new nutrients. Beneficial management involves recycling as well as the provision of new supplies where soil invertebrates are additionally important.

applications of minerals and the selection of strains of super bug are out even if the super bug is beneficial to plant species considered desirable.

Most beneficial practices involve the gradual development of the system. Some involve additions, as with the application of diverse populations of microbes together with a range of micro nutrients. Some involve modifying the soil environment, as with the Wallace plow (Yoemans keyline system). Others involve vegetation management, as with Natural Sequence Farming (NSF), and cropping by direct seeding into native grassland. The significant aspects of the different approaches are outside the scope of this note and will be addressed elsewhere.

Global Implications

The main current environmental concern relates to global warming, which has been attributed to increased levels of atmospheric CO_2 arising primarily from the burning of fossil fuels. This conclusion has been reached despite the increase in atmospheric CO_2 being commensurate with that associated with the loss of organic matter from soils due to the loss of perennial vegetation through agriculture. There is no need to invoke any reference to fossil fuels when addressing the increase in atmospheric CO_2.

The conclusion that the observed global warming arises through the insulating effect of atmospheric CO_2 has been ratified by an international scientific committee when the need to refer the issue to such a committee identifies that the situation is not at all clear. Their conclusions were sound according to the information to hand. There is a significant issue, the warming is correlated with increased levels of atmospheric CO_2, and a mechanism can be identified whereby an increase in atmospheric CO_2 could possibly produce global warming.

The implied but not explicit covenant is that the committee could not identify any other possible cause. This is embodied in the comment that, while it is not certain that global warming is caused by increased atmospheric CO_2, it is prudent to take remedial action assuming that it is. No one can be sure that increased atmospheric CO_2 is causing the observed global warming but no one can come up with an alternate plausible explanation.

This situation is a direct consequence of the scientific method. Decisions can only be based on what is known and there is much that is unknown. Also, there is no test that can be conducted to conclusively demonstrate that the increased levels of atmospheric CO_2 are responsible for global warming. Those promoting CO_2 as being the cause have taken circumstantial evidence (correlations) as representing proof when it is not, and have ignored the basic scientific requirement for testing. The most reliable test, although not failsafe due to the complex nature of the interactions involved, is the ability to reverse the effect. This obviously has not been done with atmospheric CO_2.

It will be found that the increased levels of amospheric CO_2 are an effect rather than a cause. In consequence, efforts directed at sequestering carbon from fossil fuels will serve no purpose other than to promote business and bureauchracy. The application of an eccomic/bureauchratic solution to an environmental problem, as arises with carbon credits, serves only to produce large profits for companies at extreme costs to the community, as has occurred with fertiliser and tabacco. Bureaucracies expand through developing and administering the rules and regulations.

With increased knowledge on the energy balance of the earth it will be found that the cause of global warming is directly related to vegetation clearing, hence the solution involves reestablishing viable plant communities. Soil OM is central to the development of plant communities and hence is central to addressing global warming.

Big business and governments are curently circumventing soil OM for carbon credits due to the difficulties of measurement as these introduce large administrative costs. Soil OM is being neglected for bureahchratic and business reasons. This must change if global warming is to be successfully addressed.

Discussion

This note identifies logical connections between diverse sources of information deriving from different disciplines. The contribution relates to the integration of existing information rather than the presentation of new information.

While relying on existing information the note is effectively reference free because the information used is readily available from numerous sources. Moreover, citing all relevant literature would be impossible while the presentation of selected references serves only to identify personal bias.

The only point not addressed by existing literature relates to increased CO_2 being an effect and not a cause of global warming. This is partly addressed by Tunstall (2008) and will be further addressed later, but currently the most appropriate reference is the episode of Yes Prime Miniser on The Need To Know. How do you know what you need to know until you know what there is to know? However, related points are well addressed in the literature, such as the increase in atmospheric CO_2 being commensurate with the loss of carbon. Also, logical points, such as the absence of any test to evaluate the hypothesis that global warming is caused by increased levels of atmospheric CO_2, do not rely on references for their validity. Those presenting CO_2 as definitely being the cause of global warming either do not understand the requirements of the scientific method or choose to ignore its limitations. The conclusion that increased CO_2 is the cause of global warming only arises because of the inability to identify an alternate mechanism.

Soil organic matter has been sidelined in agriculture post World Waw 2 because of the false view that fertility can be addressed using mineral fertilisers. It has been sidelined in addressing global warming because of the high costs of meeting an administrative system that uses monetary profit for its reference. It is a casuality of administrations appeasing business by applying economic ‘solutions’ to environmental problems.

If human health is to improve rather than continue its existing decline, and if global warming is to be mitigated, then increasing the levels of soil OM must receive a very high priority. Lands under agriculture, which are commonly highly degraded, or made unusable by agriculture, which means they are extreamly degraded, most urgently need attention.

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