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Research Application Summary

Soil properties effects and management of organic residues to improve C sequestration, reduce N losses and improve crop yields

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Abstract

Rates of decomposition of organic materials in soil determine the amount of carbon (C) which is mineralized and released as CO_2 versus the amount of C that is retained in various forms in the soil. Decomposition rates also greatly influence the amount of nitrogen (N) which becomes available for plant uptake or susceptible to leaching versus that which is retained in SOM or lost via gaseous emission. The processes that follow the decomposition of residues by microorganisms are strongly influenced by soil chemical and physical properties, and also by plant roots via the processes of mineral N uptake, respiration, exudation and decay. The equilibrium between carbonates, bicarbonates, CO_2 and pH controls inorganic C losses and deposition over large areas of arid and semi arid climates and should be linked to the biological cycle of C. However, few quantitative relationships between decomposition rates of organic manures & wastes (OW) and controlling edaphic, climatic and biotic variables have been determined. The overall objective of this proposal is to explore the effects of soil properties and management practices on C sequestration in soils, off-site losses of N and crop productivity. We hypothesized that organic waste decomposition is a biological process controlled by the microorganism population and it is not affected by soil properties, and that sequestration of CO_2-C by inorganic components of the soil may be a considerable process in calcareous soils. The methodology includes the simultaneous use of laboratory and field experiments with stable isotopes of N and C to follow the dynamics of N and C. Best management practices will be identified by field experiments and simulation scenarios with the process oriented computer simulation models of N and C transformations in a soil-OW-plant system (NCSOIL) and two MSc students will be trained.

Key words: Organic wastes (OW), N & C cycling, NCSOIL, modeling, C- sequestration, climate change, food security

Résumé

Les taux de décomposition des matières organiques dans le sol détermine la quantité de carbone (C) qui est minéralisé et publié sous forme de CO2 par rapport à la quantité de C qui est conservée sous diverses formes dans le sol. Les taux de décomposition également influent grandement sur la quantité d'azote (N) qui devient disponible pour les végétaux ou sensibles à la filtration par rapport à celle qui est retenue dans SOM ou perdus par des émissions gazeuses. Les processus qui suivent la décomposition des résidus par les microorganismes sont fortement influencés par la chimie du sol et les propriétés physiques, et aussi par les racines des plantes par l'intermédiaire du processus d'absorption de l'azote minéral, la respiration, l'exsudation et la pourriture. L'équilibre entre les carbonates, les bicarbonates, le CO2 et de contrôle pH inorganiques C, perd le dépôt sur de vastes zones arides et des climats semi arides et devrait être liée au cycle biologique de C. Cependant, peu de relations quantitatives entre les taux de décomposition des engrais organiques et les déchets (OW) et le contrôle des variables édaphiques, climatiques et biotiques ont été déterminées. L'objectif global de cette proposition est d'explorer les effets des propriétés du sol et des pratiques de gestion sur la séquestration du carbone dans les sols, les pertes hors du site de N et de la productivité des cultures. Nous avons supposé que la décomposition des déchets organiques est un procédé biologique contrôlé par la population de microorganismes et il n'est pas affecté par les propriétés du sol, et que la séquestration de CO2-C par des composants inorganiques du sol peut être un processus considérable dans les sols calcaires. La méthodologie comprend l'utilisation simultanée d'expériences en laboratoire et sur le terrain avec des isotopes stables de N et C de suivre la dynamique de N et de pratiques de gestion du C. Les meilleures pratiques seront identifiées par des expériences de terrain et des scénarios de simulation avec le processus orientés modèles de simulation informatique de N et C transformations dans un système sol-plante-OW (NCSOIL) et deux étudiants à la maîtrise seront formés.

Mots clés: Déchets organiques (OW), le cycle N et C, NCSOIL, la modélisation, C-séquestration du carbone, changement climatique, la sécurité alimentaire

Background

Application of organic manures and OW to agricultural soils is increasing as a result of the necessity to supply nutrients to crops, to increase or at least maintain organic matter concentrations in soil and to recycle materials for protection of the environment. With the rapid growth in population, the need to urgently address the challenges of food security as well as climate change cannot be overemphasized. Atmospheric concentration of CO_2 has increased from ~ 280 ppm in pre-industrial era to ~ 385 ppm in 2008 (+ 37.5%) and is presently increasing at the rate of ~ 2 ppm/yr (Lal, 2009). The increase in CO2 emission by human activity is attributed to fossil fuel combustion, deforestation and biomass burning, soil cultivation and drainage of wetlands or peat soils. The increase in CO_2 concentration in the atmosphere which is associated to an elevation in global temperature with potentially disastrous consequences has triggered a flurry of international and national programs to sequester C in soil in an attempt to reduce the "greenhouse" effect. The UN Intergovernmental Panel on Climate Change ("Climate Change 2001: Mitigation") recognizes the possibility of carbon sequestration "using biospheric processes to remove C from the atmosphere and transport it to the deep ocean", but potential of the terrestrial sink has apparently been overlooked. Carbonate deposition is a well documented feature of soil formation over large areas of arid and semi-arid climates. Yet, the dynamics of inorganic C (CO_2-bicarbonates-carbonates) and its interaction with the organic C cycle has not been considered in current models of global climate change. Increased soil carbon storage through improved manure management to reduce CH_4 emissions; composting of organic wastes, and improvements of crop yields are important (IPCC, 2007).

The kinetics of OW decay has been studied and incorporated in simulation models which are used to identify the best management scenarios to apply OW. This approach is seriously biased because these models do not incorporate inorganic C transformations (carbonate-bicarbonate-CO_2 equilibrium) and the release of C from roots by respiration and C and N by exudation - processes that contribute to C input to soil and affect the rates of organic matter decomposition through changes in the soil pH and inorganic N availability for N immobilization by the decomposers.

Mitigation of the greenhouse effect by C sequestration should not be achieved to the detriment of other goals e.g. crop production, water and air quality. It would not be good practice for example, to pollute the water table with nitrate and release nitrous oxides at the soil/air interface through the massive addition of manure for the sake of higher levels of crop production and C sequestration. N and C dynamics are linked and the management practices that strike an optimum balance between various agronomic and environmental goals should be identified.

Literature Summary

The rate of OW decomposition and the fraction of decayed OW-C released as CO_2 depend on the availability of N for optimum growth of the decomposing microbial population (Molina *et al.*, 1983). Application of Organic manures and other OWs as composts is preferred, being a more hygienic and uniform product than the raw material. However, the composting process stabilizes available N and reduces the value of manure as N fertilizers (Castellanos and Pratt, 1981). The capacity of soil to retain organic matter is thought to be dependent on soil texture, as fine-textured soils usually contain more organic matter than coarse-textured soils that have received the same input of organic material during a long period of time (Jenkinson, 1988).

The equilibrium between carbonates, bicarbonates, CO_2 and pH controls inorganic C losses and deposition over large areas of arid and semi arid climates and should be linked to the biological cycle of C. The chemistry of carbonates and Ca or Mg is well documented and the process governing CO_2 evolution from soils is a chain of chemical transformations. The following reactions govern mineral C speciation in the soil solution. $CO_{2(aq)} + OH^- \rightleftharpoons HCO_3^-{}_{(aq)}$ [1]. Consequently, CO_2 dissolution in the soil solution acidifies the solution. Bicarbonate may react with protons forming the chemical equilibrium equation: $CO_{2(aq)} + H_2O \rightleftharpoons H_2CO_{3\,(aq)}$ [2]. Protons are released to the soil solution during the decomposition of organic matter to produce CO_2. Simunek and Suarez (1993) developed a model for the above described CO_2-H_2O system. The dissolution of Calcium and Mg carbonates can be described by the reactions:

Calcite: $CaCO_{3(s)} + 2H^+ \rightleftharpoons Ca^{2+} + H_2CO_{3\,(aq)}$ .... (3)

Nesquehonite: $MgCO_3 3\,H_2O_{(s)} + 2H^+ \rightleftharpoons Mg^{2+} + H_2CO_{3\,(aq)} + 3\,H_2O$ .... (4)

Hydromagnesite: $Mg_5(CO_3)_4(OH)_2 3\,H_2O_{(s)} + 10H^+ \rightleftharpoons 5Mg^{2+} + 4H_2CO_{3\,(aq)} + 5\,H_2O$ .... (5)

Thus CO_2 released in soil may be captured and deposited as carbonates. Many models have been developed to simulate organic material decomposition and N cycling in soil. Among them is NCSOIL (Molina et al., 1983; Hadas and Molina, 1993), a well tested model that involves N and C and their tracers cycling in soil with organic residues. This model has been used to evaluate rates of decomposition and available N released from composts and plant residues (Hadas *et al.*, 1993; Hadas and Portnoy, 1994). There is a potential to apply it for long term simulations in well designed experiments of OW application.

Study Description

Field experiments. Field experiments will be conducted for two years at two sites. Soils obtained from different sites / locations in Kenya will be screened for contrasting properties - texture, carbonate content, pH, CEC, to determine the exact location of the two sites (One site with calcareous soil (eg Marigat), other in humid climate with clay, low pH eg at Kabete) to study the effects of two types of organic manures (compost and maize residues) and their management (surface and subsurface) on N and C cycling and yield of maize. The study will commence long rains March, 2011. The experimental design will be factorial treatments in randomized three blocks. The treatments include 1. Compost manure surface applied 2. Compost manure Incorporated 3. Maize residues surface applied 4. Maize residues incorporated 5. A control is included. Each treatment will be replicated three times. Maize (*Zea mays*) will be used as a test crop. The plot size will be 6m x 6 m. Maize will be planted in April and harvested in mid August. The surface treatment will be without tillage whereas in the subsurface a shallow tillage by disking will be employed 4 weeks before planting to incorporate the OW into the top 15 cm soil layer. Soil samples of the 0-10, 10-20, 20-30, 30-60, 60-90 cm depth will be taken from each plot before sowing, at flowering, at anthesis and after harvest. Plants will be sampled for dry matter production and N content. The dynamics of C and N transformations in the soil/corn system will be studied using tracer ^{15}N (with residues of ^{15}N enriched corn). Plant samples will be dried at 65°c and analyzed for dry weight and %N by wet digestion with sulfuric acid and peroxide. The soil samples will be dried at 45°c and analyzed for ammonium and nitrate in 1N KCl extract. The pH, EC and the concentrations of bicarbonate and carbonate, NO_3, PO_4, SO_4, Cl, NH_4, Ca, Mg, Na and K as well as dissolved organic C will be determined in 1:1 soil to water extracts. Gases losses of C and N will be collected in traps made of PVC pipes (4" i.d., 81 cm^2 surface area). The air samples will be analyzed by GC for CO_2, N_2O, N_2 and O_2. During the first 2 weeks.

Laboratory incubation experiments and modelling. Laboratory incubation experiments will be set up to study to determine the rate of organic wastes decomposition for calibration of the relevant parameters in NCSOIL and to explore the effects of soil properties on the transformations of C and N in soil. It will include four soils, two from the field experiment sites with contrasting clay, CEC and carbonate contents. In addition soils with different levels of clay and carbonate will be produced by mixtures of the sandy soil (from Lodwar) with the soils that contain the highest amounts of clay (Kabete nitisol) and carbonate (from Marigat). The soils will be amended with manures and crop residues according to their C content to obtain 2 g kg^{-1} soil and their decomposition studied in controlled conditions of temperature (30p C) and moisture (60% WHC) for 0, 1, 2, 3, 7 days and 2, 3, 4, 8, 12, 16, 24, 32, and 40 weeks, three replicates for each combination at each interval. Measurements include pH, EC, Total carbonates and bicarbonate (using an automatic acid titrator), CO_2 emission rate (by trapping in 1N NaOH), NO_3, SO_4, Cl and NH_4 using the Lachat Autoanalyzer, Ca and Mg using atomic absorption, Na and K using flame photometry. Total N and organic C will be determined in the initial and final samples. Existing model, NCSOIL will be used to compute the rates of organic material decomposition and to explore the quantitative effects of soil properties (texture and CEC), inorganic C (CO_2-bicarbonates-carbonates equilibrium) and plants, on C and N transformations following added organic matter decomposition.

Research Application

The study on the mineral sequestration of C in soil will contribute to the understanding of the global C balance how it can be further managed to reduce gaseous losses to the atmosphere. The results obtained with NCSOIL simulation will identify the conditions that favour mineral C sequestration in soil. The model will suggest management scenarios that increase biological C sequestration with minimal air and water N pollution. The quantitative study of the effect of soil properties on the fate of the applied C and N will improve the adjustment of organic manure & waste management to soil type and to sustainably manage the resources for improved crop yields, water and air quality. The research is also expected to train two MSc students.

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