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Modelling Release of Nutrients from Organic Resources Using APSIM

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Abstract

In the context of integrated nutrient management, the performance of a crop model depends mainly on its ability to adequately describe the release of nutrients from diverse inputs and their uptake by the crop. The wide range of input materials found in tropical farming systems brings new challenges for modelling. In particular there are ‘quality factors’ that influence the decomposition and nutrient-release processes, while the range of manures encountered are quite different, both physically and chemically, from plant residues.

The APSIM modelling framework contains a set of biophysical modules that can be configured to simulate biological and physical processes in farming systems. In terms of the dynamics of both carbon and nitrogen in soil, APSIM SoilN deals with the below-ground aspects, and APSIM RESIDUE with the above-ground crop residues. APSIM MANURE is a recent addition to simulate nutrient availability to crops following addition of materials of highly variable carbon and nitrogen content. It has not been widely tested against measured field-response data.

The objectives of the ACIAR-funded project LWR2/1999/03 ‘Integrated nutrient management in tropical cropping systems: improved capabilities in modelling and recommendations’, were to evaluate and enhance capabilities in APSIM to predict nutrient availability and subsequent crop growth following the addition of organic and inorganic sources of N and P. This paper briefly describes the capabilities of APSIM to simulate the dynamics of N as they existed at the start of the project.

Models that simulate the growth of crops have been around for more than 40 years. In order that they respond sensibly to climate, soil and management, such models tend to have similar features. Notably, they need to represent the processes that are understood to occur. Typically, they operate at a daily time-step, reflecting on the one hand the availability of weather data, and on the other the fact that this is an appropriate time-step for capturing the more important effects of management on the supply of nutrients and water from the soil and demand by the plant.

Of the many factors that potentially affect the growth of plants, the two that are most responsive to management are water and nitrogen. It is therefore not surprising that most crop models include routines to handle responses to water and nitrogen. Less frequently do models attempt to describe limitations due to other soil constraints (Probert and Keating 2000).

In the context of integrated nutrient management, the performance of a model depends mainly on its ability to adequately describe the release of nutrients from diverse inputs and their uptake by the crop. In many situations, especially in low input agricultural systems in the developing world, crop growth is limited by nutrients other than N, particularly by

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inadequate phosphorus. Accordingly, to be useful for exploring strategies for improving crop nutrition of crops, models need to predict the responses to both N and P. The main objectives of the ACIAR-funded project LWR2/1999/03 'Integrated nutrient management in tropical cropping systems: improved capabilities in modelling and recommendations' were to evaluate and enhance the capabilities in APSIM (McCown et al. 1996; Keating et al. 2003) to predict nutrient availability and subsequent crop growth following the addition of organic and inorganic sources of N and P.

In this paper, we briefly describe the capabilities of APSIM to simulate the dynamics of N as they existed at the start of the ACIAR project. Other papers in these proceedings will report on efforts to improve the ability to describe the release of N from materials typical of those used in many tropical farming systems (Probert et al. 2004), and the new capability to simulate response to P-limiting conditions (Probert 2004).

The Agricultural Production Systems Simulator (APSIM)

The APSIM modelling framework contains a set of biophysical modules that can be configured to simulate biological and physical processes in farming systems (Keating et al. 2003; web site <www.apsim.info>). The foremost reason for its development was as a modelling framework for simulation of cropping systems in response to climate and management.

Two modules provide the representation within APSIM of the dynamics of both carbon and nitrogen in soil. APSIM SoilN deals with the below-ground aspects, and APSIM RESIDUE with the above-ground crop residues. These modules have been described by Probert et al. (1998).

Soil organic matter and nitrogen

APSIM SoilN is the module that simulates the mineralisation of nitrogen and thus the N supply available to a crop from the soil and residues/roots from previous crops. Its development (Probert et al. 1998) can be traced back via CERES models (e.g. Jones and Kiniry 1986) to PAPRAN (Seligman and van Keulen 1981). SoilN provides an explicit balance for carbon and nitrogen so that it is better able to deal with longer-term changes in soil organic matter.

The greatest change from CERES is that the soil organic matter in SoilN is treated as a three pool system, instead of the two pools used in CERES (see Figure 1). The dynamics of soil organic matter is simulated in all soil layers. Crop residues or roots added to the soil comprise the fresh organic matter pool (FOM). Decomposition of FOM results in formation of soil organic matter comprising the soil microbial biomass (BIOM) and HUM pools. The BIOM pool is notionally the more labile organic matter associated with soil microbial biomass; while it makes up a relatively small part of the total soil organic matter, it

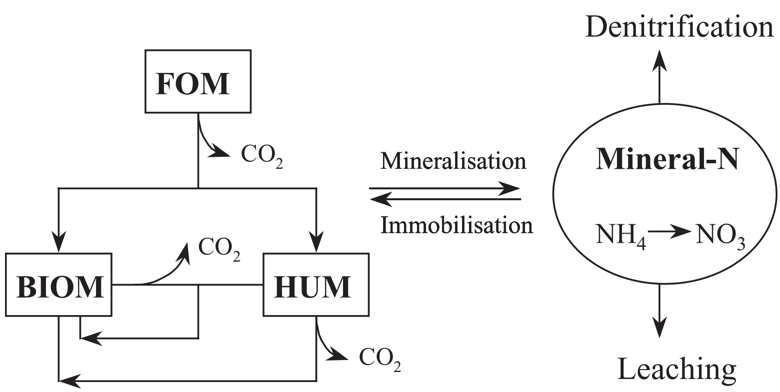

Figure 1. Schematic representation of the processes affecting soil organic matter and nitrogen transformations in the APSIM SoilN module. FOM = fresh organic matter, i.e. roots and incorporated crop residues; BIOM = labile soil organic matter pool; HUM = remainder of soil organic matter.

has a higher rate of turnover than the bulk of the soil organic matter.

The reasons for introduction of an additional soil organic matter pool were to better represent situations where ‘soil fertility’ improves following a legume ley (Dimes 1996). A single soil organic matter pool cannot deal realistically with the changes in mineral N supply following the cumulative additions of high N material to soil organic matter. The concepts depicted in Figure 1 have much in common with other models, such as the Rothamsted Nitrogen Turnover Model (Bradbury et al. 1993).

The release of nitrogen from the decomposing organic matter pools is determined by the mineralisation and immobilisation processes that are occurring. The carbon that is decomposed is either evolved as CO_2 or is synthesised into soil organic matter. SoilN assumes that the pathway for synthesis of stable soil organic matter is predominantly through initial formation of BIOM, though some carbon may be transferred directly to the more stable pool (HUM). The model further assumes that the soil organic matter pools (BIOM and HUM) have C:N ratios that are unchanging through time. The C:N ratio of the BIOM pool is typically set at 8, while that of the HUM pool is based on the C:N ratio of the soil, which is an input at initialisation of a simulation. The formation of BIOM and HUM thus creates an immobilisation demand that has to be met from the N released from the decomposing pools and/or by drawing on the mineral N (ammonium and nitrate) in the layer. Any release of N above the immobilisation demand during the decomposition process results in an increase in the ammonium-N.

The FOM pool is assumed to comprise three subfractions (FPOOLs), sometimes referred to as carbohydrate-, cellulose- and lignin-like, each with a different rate of decomposition. In this manner, the decomposition of added plant material under conditions of constant moisture and temperature is not a simple first-order process.

The rates of decomposition of the various soil organic matter pools are dependent on the temperature and moisture content of the soil layers where decomposition is occurring. In circumstances where there is inadequate mineral N to meet an immobilisation demand, as can occur where the C:N ratio of the FOM pool is high, the decomposition process is limited by the N available to be immobilised.

Other processes dealt with in SoilN are nitrification, denitrification and urea hydrolysis (following application of urea as fertiliser). Fluxes of nitrate-N between adjoining soil layers are calculated based on movement of water by the water balance module. Ammonium-N and all soil organic matter pools are assumed to be non-mobile.

Surface residues

In APSIM, crop residues that are on the soil surface are handled by the RESIDUE module (see Figure 2), described by Probert et al. (1998). This has been done so that surface residues can affect the soil water balance through run-off and evaporation.

Crop residues are accounted for as a single surface residue pool that is described in terms of its mass, the cover it provides for the soil surface, and its nitrogen content. When new residues are added, either because of senescence and detachment or at harvest, new weighted (mass) average values are calculated to describe the total amount of residues present.

The amount of residue decreases through one of three processes. Firstly, by removal of residue (for example by burning or collection for animal feed); such action does not alter the C:N ratio of the residues. Secondly, through the incorporation of residues into the soil. A tillage event transfers a specified proportion of the surface residues into the soil FOM pools to a nominated depth. Finally, by decomposition *in situ*. The decomposition routine is similar to that used for the soil organic matter pools in the SoilN module in order to maintain balances of both carbon and N. Any immobilisation demand is met from the uppermost soil layer, while the soil organic matter formed and ammonium-N mineralised are added to the uppermost soil layer. The temperature dependency for decomposition of residues is related to daily ambient temperature. As the soil water balance does not include the litter layer, the moisture dependency is assumed to be unconstrained immediately after a rainfall event, with decomposition rate declining as litter dries, based on potential evaporation. The rate of decomposition is also sensitive to the amount of residues on the soil surface. A ‘contact’ factor accounts for the opposing effects of mulch separation from the soil surface and a modified moisture environment in the mulch layer as the amount of surface material increases. Thorburn et al. (2001) have investigated the importance of the contact factor for sugarcane systems that involve large amounts of surface residues (up to 20 t ha^{-1}).

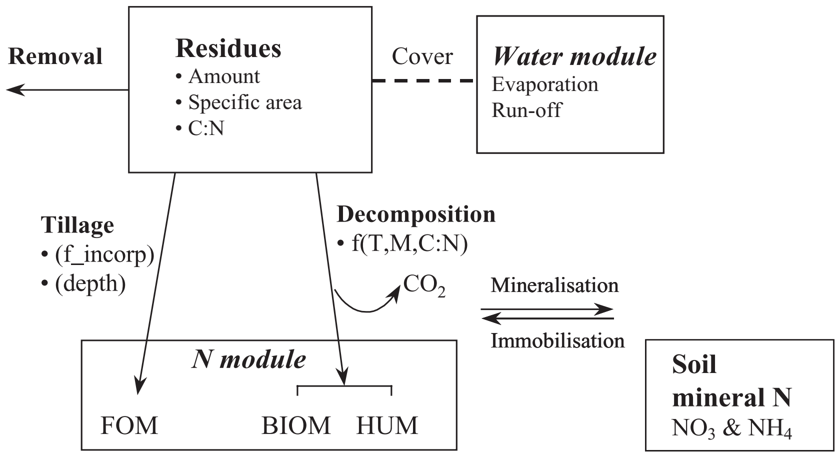

Figure 2. Schematic representation of the processes dealt with in the APSIM RESIDUE module. Note the linkage with the water module whereby the amount of residues will influence components of the water balance.

Manures

In many low-input systems, manures are the sole source of nutrients applied to croplands. These manures are often of low quality. Studies in eastern Kenya (Probert et al. 1995) have shown that the manures being used on farms are grossly inadequate as a source of nitrogen, and are probably being used inefficiently as a source of phosphorus. This is true also in other parts of the semi-arid tropics.

In these environments, improved management of soil fertility calls for efficient use of scarce supplies of manure, integrating its use with other sources of nutrients in crop residues (particularly where legumes are grown) and augmenting these sources where necessary with purchased fertilisers. It is the location of this complexity of nutrient supply investments in a climate with high rainfall uncertainty that makes a simulation model a valuable tool for comparing management options. But, to be useful, the simulation model must adequately represent the nutrient value of the manures, involving their decomposition patterns and the availability of the nutrients for crop growth.

The development of the APSIM MANURE module has progressed towards filling this need. It should be noted that the concern has been with farming systems employing generally low quality manure that is normally incorporated into soil before sowing. Had the interests evolved elsewhere, with higher quality manures and slurries, say, as occur in intensive livestock systems, the approaches taken may have been different (e.g. volatilisation losses as ammonia).

Manures vary greatly in composition (Lekasi et al. 2003), being a complex mixture of animal excreta and plant residues that has undergone varying degrees of composting/decomposition and might have been mixed with considerable amounts of soil (as in the Kenyan boma system; Probert et al. 1995). Some of the nutrients are in forms that are immediately available for uptake by plants, and some will have to undergo decomposition before they become available. This concept of nutrient availability implies a time dimension, with the nutrients in manure exhibiting a wide range of availabilities, ranging from components that are water soluble to very recalcitrant.

A simple characterisation is to divide each nutrient into two fractions: one part that is immediately available with the rest being treated as an initially unavailable, organic input that must decompose in order for its nutrients to become available. The concept for the organic portion has obvious similarities with how APSIM represents decomposition of crop residues and roots, but with two important differences. In crop residues, carbon content varies little (Palm et al. 2001), and for most plant material APSIM assumes 40% in the dry matter; this is not so for manures.

Also, APSIM SoilN assumes that the carbon in crop residues and roots added to the soil FOM is distributed between the three FPOOLs in the ratio 20:70:10; one suspects that this would not hold true for manures.

The schema for the APSIM MANURE module is shown in Figure 3. An application of manure is specified in terms of its mineral N components and the organic portion. For a surface application, it is assumed that the mineral components are leached into soil in response to rainfall, and the organic portion will decompose *in situ* in an analogous manner to decomposition of surface residues. Incorporation of the manure transfers both the mineral and organic components into the soil to the specified depth, with the organic portion becoming part of the FOM in the APSIM SoilN module.

In early tests of the sensibility of the MANURE module it was supposed that different quality manure could be represented by variation in the FPOOLs comprising the organic fraction (e.g. Carberry et al. 2002). The paper by Probert et al. (2004) explores the extent to which this is feasible.

Discussion

Models have evolved as they have been applied to different agricultural systems, and this is particularly true for the simulation of nutrient dynamics. It is instructive to reflect on the relatively short history that covers the development of APSIM to its present capability.

The early modelling experiences of those who were to become the developers of APSIM were with models of the CERES family, particularly CERES-Maize (Jones and Kiniry 1986). These models had been developed primarily to simulate the growth of crops in high-input systems. As long as N fertiliser inputs met a substantial proportion of the crop nutrient needs there was not much pressure on the model to accurately predict N mineralisation from soil.

However, attempts to apply such models to low-input systems exposed this problem, and efforts were made to improve the soil mineralisation routines (Probert et al. 1998). In particular, it was recognised that a full accounting of both C and N was needed,

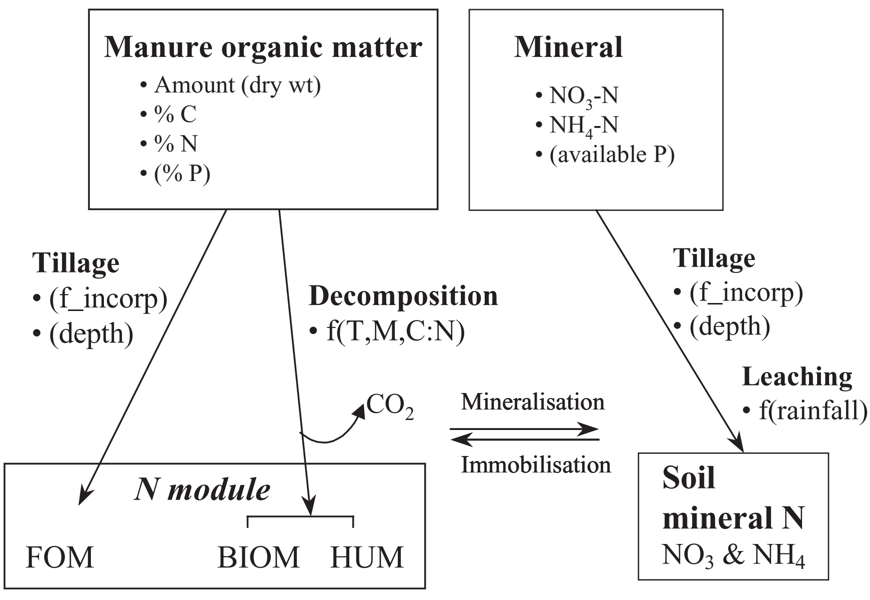

Figure 3. Diagram showing processes considered in the APSIM MANURE module. Manure on the surface of the soil can have an effect on the water balance in similar manner to surface residues (not shown). The schema has provision for manure to also contain phosphorus, which would be transferred to the APSIM SoilP module when manure is incorporated into soil or decomposes.

and that all soil organic matter was not the same with respect to its susceptibility to decomposition (this latter effect being particularly important with soil organic matter in subsoil layers).

Modelling the growth of single crops, with the soil being initialised just before sowing, masked the ability of the models to adequately represent crop residues and roots. Indeed, many crop models can do a satisfactory job in predicting crop yields without considering roots (e.g. the RESCAP model of Monteith et al. (1989)). The desire to model sequences of crops (i.e. a true farming system rather than a single crop) exposes such inadequacies. The amount of roots and residues remaining, and their quality, have major effects on the N supply to following crops. These might be positive in the case of a legume–cereal sequence, or detrimental when cereal residues with a high C:N ratio cause immobilisation of N. For the materials encountered in typical arable cropping systems, the mineralisation/immobilisation of N can be represented as the outcome of the decomposition of the organic sources and the synthesis of soil organic matter. In such materials, the carbon concentration in close to 40%, and concentrations of lignin and polyphenols are generally small. Thus, N concentration (or C:N ratio) is the dominant factor controlling N release.

Most recently there has been recognition of the need to simulate the nutrient release from a wider range of organic inputs, especially manures. For example, Palm et al. (1997) asserted

> ... current simulation models do not yet fully meet the needs of research and extension workers in developing countries ... The major issues that need attention are the capacity to simulate P dynamics and the decomposition of the range of crop residues and organic materials that are encountered in tropical farming systems.

The wider range of materials found in tropical systems brings new challenges for modelling. In particular, there are other 'quality factors' that influence the decomposition and nutrient release processes (Heal et al. 1997), while the manures encountered are quite different, both physically and chemically, from plant residues. The purpose of the project reported in these proceedings was to evaluate current predictive performance of APSIM in these tropical farming systems, and to implement further improvements to the model based on understanding of the experimental data.

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