Modelling Nutrient Management in Tropical Cropping Systems

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Preface

In tropical regions, organic materials are often more important than fertilisers in maintaining soil fertility, yet fertiliser recommendations and most crop models are unable to take account of the level and quality of organic inputs that farmers use.

Computer simulation models, such as the Agricultural Production Systems Simulator (APSIM) developed by CSIRO and the Queensland Department of Primary Industries, have proven their value in many cropping environments. These proceedings report the results of an ACIAR-supported project to test and improve the capability of APSIM to predict the decomposition of various organic inputs, the dynamics of nitrogen and phosphorus in soil, and crop yields. They document the achievements of the project and show the benefits of linking laboratory, field and modelling studies.

Another activity of the project was to train and support national collaborators in East and southern Africa in the use of APSIM for integrated, nutrient-management practices.

The project was implemented through the Soil, Water and Nutrient Management Consortium (SWNM) of the Consultative Group on International Agricultural Research (CGIAR). Project partners came from a number of institutions with an interest in simulation modelling and nitrogen and phosphorus dynamics.

As a result of this project, the APSIM computer model has been enhanced in several areas and tested against long-term data sets. The information gained will be widely used by researchers and extension services in the tropics.

Peter Core
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ACIAR

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Introduction

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These proceedings derive from the end-of-project meeting of the ACIAR-funded project 'Integrated nutrient management in tropical cropping systems: improved capabilities in modelling and recommendations' (Project no. LWR2/1999/003). The meeting was held in Nairobi, Kenya in January 2003. The project was managed by the Tropical Soil Biology and Fertility Institute for the Soil, Water, and Nutrient Management consortium of the Consultative Group on International Agricultural Research (CGIAR), in collaboration with CSIRO Sustainable Ecosystems/Agricultural Production Systems Research Unit (APSRU).

Smallholder farmers in the tropics rely to a large extent on organic inputs and biological processes for managing soil fertility. Biologically based farming systems range from annual cropping and fallow rotations involving biologically fixed nitrogen, to intensive continuous cropping with additions of manures and/or composts, that may be augmented with inorganic fertilisers. There has been considerable advance in the past decade in understanding the role of organic materials in soil-nutrient availability and maintenance of soil organic matter. Models that can simulate nutrient release patterns according to the resource quality, soil conditions, and climate would provide a means of making initial recommendations for testing with farmers according to their resource availability and soil management practices. Currently, crop and ecosystem models do not include appropriate routines for simulating nitrogen dynamics following incorporation of organic inputs of the diverse nature found in tropical cropping systems.

Another major gap in soil fertility recommendations for the tropics is that of phosphorus management. Crop production on many of the soils in the tropics is limited primarily by phosphorus. Our understanding of soil phosphorus dynamics and indicators of phosphorus availability lags far behind that for nitrogen. Part of the problem in modelling phosphorus is in its complex biogeochemical cycle. To date, no crop or ecosystems model has adequately captured phosphorus dynamics for estimating crop (or ecosystem) production. Considerable data have been gathered on phosphorus dynamics and soil phosphorus fractions in relation to plant productivity from a variety of soil types and management conditions in the tropics. As well as being crucial for improving understanding of P in the soil–plant system and P management, the data can be used for developing phosphorus routines of crop and ecosystem production models.

The APSIM modelling framework (Keating et al. 2003; web site <www.apsim.info>) was selected for this project because it is one of the most appropriate models for use in tropical soil and crop management. This model provides not only the short time-step essential for simulating effects of management on nutrient availability and crop growth, but also incorporates longer-term effects of changes in soil organic matter content on N mineralisation and hence on crop growth. Selection of APSIM was also based on efforts by APSRU towards developing modules to describe the release of nutrients (N and P) from added organic inputs (APSIM 'Manure'), the dynamics of phosphorus in soil (APSIM 'SoilP'), and routines within the 'Maize' crop module to limit

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growth due to inadequate supply of P in addition to nitrogen and water constraints. These modules provided a framework necessary for simulating the effects of diverse organic inputs on cropping systems found in tropical regions. Once a model has been tested and verified for a particular purpose, in this case the combined use of organic and inorganic nutrient sources, it can be a valuable tool in focusing research and ultimately for making recommendations for crop and soil management.

Project partners came from a range of institutions with an interest in simulation modelling and N and P dynamics. These partners were:

Kenya

- International Centre for Research in Agro-Forestry (ICRAF)
- International Livestock Research Institute (ILRI)
- Kenya Agricultural Research Institute (KARI)
- Tropical Soil Biology and Fertility (TSBF) Institute

Zimbabwe

- International Maize and Wheat Improvement Center (CIMMYT)
- International Crop Research Institute for the Semi-arid Tropics (ICRISAT)
- TSBF – Southern Africa Soil Fertility Network

Colombia

- International Center for Tropical Agriculture (CIAT)
- Colombian Corporation of Farming Investigation (CORPOICA)

Southeast Asia

- International Board for Soil Research and Management (IBSRAM), with national partners

Project Planning and Operations

The purpose of the project was to develop a modelling capability that can be applied to farming systems where both organic and inorganic sources of nutrients are used. In tropical regions, organic materials are often more important for maintenance of soil fertility than fertilisers, yet current fertiliser recommendations and most crop models are unable to take account of the organic inputs and the different qualities of these organic inputs that farmers use. This project tested and, where necessary, improved the APSIM Manure and SoilP modules so that they can be applied to the management of soil fertility, especially in low-input systems in the tropics.

A project implementation workshop in 1999 brought together 25 participants with experience in the management of organic inputs and phosphorus dynamics in soil. At the workshop, decisions were made on the nature of the data sets needed to test the model and where new data were to be collected so that they are compatible with inputs required by APSIM.

During the project, meetings were held in Nairobi to familiarise collaborators with APSIM, train them in APSIM use, and to compile data sets for testing and evaluating the Manure and SoilP modules. Any code changes required within APSIM were done in Australia by APSRU, and modified versions of the modules were tested in subsequent workshops. Outside of these formal workshops, modelling support was provided in East and southern Africa, as well as in Asia, to continue developing the data sets, modelling work and support to APSIM users.

Project Objectives

The project objectives were:

- to collate and synthesise data from existing trials compatible with the requirements of APSIM for testing and modification of the manure and phosphorus modules
- to strengthen the capability of APSIM to predict nutrient availability and subsequent crop growth following the addition of organic and inorganic nitrogen and phosphorus nutrient sources
- to train and support national collaborators in East and southern Africa in the use of APSIM for integrated nutrient management practices.

Project Outcomes

These proceedings document the achievements of the project and show the benefits from linking laboratory, field and modelling studies. Resource-poor farmers face difficult decisions over the use of scarce nutrient sources in production systems. Efforts are required to expand our knowledge of the biophysical aspects of alternative uses of organic nutrient sources and also the socioeconomic driving forces behind farmers' decision-making (Chapter 2.1). Often the decisions on the use of organic resources are taken without an assessment or appreciation of the impact of alternative uses on plant production and on soil and water resources. While existing simulation models are able to simulate responses of crops to, for example, inorganic fertiliser additions, there are still gaps in our ability to simulate short and long-term effects of additions of different organic N and organic and inorganic P resources (Chapter 2.2). A deeper understanding from the farmers' perspective of the comparative values and usefulness of manures and other locally available resources is required in order to increase the production and efficiency of their production systems and to be able to target improved management options using participatory approaches (Chapter 2.3).

Consideration of the influence of organic resource quality on nutrient management and nutrient release dynamics, introduced in Chapter 2.1, is expanded in Section 3. These chapters cover different analytical techniques for measuring resource quality, and relate the resource quality factors to the mineralisation of nitrogen. It is the understanding that comes from such studies that needs to be represented in the models, with the indicators that can be measured being used to parameterise the models.

Simulation models were not able to mimic the complex pattern of N release that has been reported for some animal manures, notably materials that exhibit initial immobilisation of N even when the C:N of the material suggests it should mineralise N. The APSIM SoilN module was tested against existing data sets and modified so that the three pools that constitute added organic matter could be specified in terms of both the fraction of carbon in each pool and also their C:N ratios; previously it has been assumed that all pools have the same C:N ratio (Chapter 4.1). The revised Manure module is better able to simulate the general patterns on N mineralised that have been reported for different quality manures (Chapters 4.1 and 4.2). Attempting to simulate P mineralisation from organic sources in a manner analogous to that done for N results in the P concentration required for net mineralisation being much higher than found experimentally. It is suggested that this arises because much of the P is water soluble. It is expected that specifying the C:P ratio of each pool will overcome this anomaly.

The APSIM Maize module was enhanced so that uptake of P was determined by the availability of P in the soil, the P in the plant was partitioned between the plant components, and crop growth was influenced by the P status of the plant (Chapter 4.3). This 'P-aware' maize module was a major breakthrough in our thinking of how to explicitly reflect P dynamics, and especially P limitations in crop simulations. Further fieldwork has been initiated using funds from other donors to produce the data required to parameterise other crop modules, specifically cowpea and millet (in West Africa, funded by IFDC), pigeonpea, groundnut and sorghum (in India, funded by the UK Department for International Development) and canola (in Australia funded by CSIRO and the Grains Research and Development Corporation).

In this project the SoilP, Manure and Maize modules have been tested against three long-term data sets from western Kenya (Chapter 4.4), central Kenya (Chapter 4.5) and India (Chapter 4.6).

Conclusions

The APSIM model now includes a capability to simulate the N and P dynamics from different quality manures and their effects on crop growth. There is only one other modelling group that is working on soil P routines and limiting simulated plant growth as a consequence of a P constraint (Daroub et al. 2003).

This project has contributed to the improvement and validation of the APSIM Manure and SoilP modules. The organic resource quality parameters and methods for measuring them that have been identified through this project provide more relevant and streamlined data collection protocols for model parameterisation. Ultimately, the project outputs will contribute to improving the capacity to make recommendations to farmers on better management of nitrogen and phosphorus nutrient sources for crop production.

The improved management of soil fertility needs to be evaluated from economic, social, and environmental perspectives. From the economic sense, combinations of organic and inorganic nutrient sources need to be identified that increase and maintain crop production. This evaluation should include differences in both the short and longer-term benefits. From the social and economic sense, organic resources identified can substitute for mineral fertilisers in areas where fertilisers are not available or affordable. From an environmental aspect, management practices could be identified that would result in smaller losses of nutrients and would rebuild or maintain the soil resource base.

The modified model and protocols resulting from this research are applicable to researchers and extension services in the tropics. At the national levels, the teams trained in the use of the model could provide guidelines and recommendations for both researchers and extension services on the types of organic inputs, and their appropriate combinations with mineral fertilisers, that should provide the best short and long-term effects. Such recommendations could be used for designing long-term experiments for verifying model predictions or directly for achieving impact on-farm.

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