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Improved Capabilities in Modelling and Recommendations: Summary

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The purpose of the project 'Integrated nutrient management in tropical cropping systems: improved capabilities in modelling and recommendations' (ACIAR Project no. LWR2/1999/03) was to test and enhance 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 used by farmers.

When the project commenced, simulation modelling had a limited ability to predict the effects on soil processes and crop growth of organic sources that differed in 'quality'. APSIM was chosen because it had draft modules to describe the release of nutrients (both nitrogen and phosphorus) from manures (Manure module) and the dynamics of P in soil (SoilP module), and it contained routines to limit crop growth under conditions of water, N and P stress. At the start of the project, these modules were largely untested. The 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.

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Developments in Improving APSIM Manure and SoilP Modules

Resource-poor farmers regularly make decisions on the use of scarce nutrient sources in crop–livestock production systems. The decisions made generally reflect farmer experience (of expected returns) and livelihood preferences. However, for resource-poor farmers, 'experience' is often limited by the feasibility and capability of the farmer to experiment with alternative management practices. In the case of allocating animal manure for crop production, this decision is usually taken with limited knowledge of the impact of the potential of alternative uses on plant production and soil and water resources. A deeper understanding of the comparative values and usefulness of manures and other locally available resources and sources of P would help fill such knowledge gaps, offering the possibility for increased production and efficiency of mixed crop–livestock systems. While efforts are required to expand our knowledge of the biophysical aspects of alternative uses of organic nutrient sources, similar efforts are also required on the socioeconomic driving forces behind farmers' decision-making.

Cross-method analysis of plant quality

N content or C:N ratio are the primary indicators of decomposition and N release across a range of plant materials of different quality. However, other parameters (such as lignin and polyphenolics) are needed to explain the variation observed in N mineralisation studies.

Measurements for assessing plant resource quality include an extensive array of proximate analyses (lignin, acid-detergent fibre (ADF), total soluble polyphenolics, and a variety of condensed tannins). Decomposition is determined by the combination of these different factors. Indirect methods that can serve as 'integrative measures' of resource quality are discussed in Section 3 of these proceedings. These include aerobic decomposition, near infrared reflectometry (NIR) and in vitro dry matter digestibility. Results from these integrative methods correlated well with mineralisation rates estimated in the traditional leaching tube experiment and have the potential to predict this laboratory estimation of resource quality.

From this cross-method analysis, the minimum data set to assess organic resource quality consists of N, lignin, and soluble polyphenol content. This finding is consistent with conclusions from earlier efforts. Considerations of cost and speed also need to be compared where more than one method is available. Aerobic incubations are one of the cheapest but slowest methods, whereas NIR is the fastest. Although NIR instrumentation is expensive to set up, for routine analysis of many samples it could become cost effective. Construction of spectral calibration libraries in centralised laboratory facilities would greatly increase the efficiency of NIRS use for routine organic resource characterisation in laboratories and dramatically reduce the costs of such analyses.

Modifying and testing the APSIM Manure module

Existing laboratory incubation experiments and SWNM network trials in East and southern Africa situated in diverse agro-ecological zones and soil types were used to test the manure module (see Section 4). The field experiments used manures of differing quality and combined organic and inorganic sources of N. These trials provided data on the short and long-term effects on nitrogen availability, soil organic matter and crop production — information that is necessary for testing APSIM and to provide the insights needed for making any modifications to APSIM.

Initially, as in other models of soil organic matter turnover, the model assumed that the soil organic matter pools (BIOM and HUM) have C:N ratios that are unchanging during the decomposition process. Additions of fresh organic matter (FOM) are considered to comprise three pools (FPOOLs): the carbohydrate-like, cellulose-like and lignin-like fractions. Each FPOOL has its own rate of decomposition, which is modified by factors to allow for effects of soil temperature and soil moisture. Although the three fractions have different rates of decomposition, they did not have different compositions in terms of C and N content. During this project we concluded that, to simulate release of N from diverse sources of manure, the model could match observed short-term release patterns only if the pools had different C:N ratios. This insight came from the results of laboratory studies that showed variable N-release patterns depending on the C:N ratio of the soluble fraction of the manures (Probert et al., these proceedings). The APSIM Manure module has been modified so that the pools can now be specified to have different C:N ratios. This enabled the effects of different qualities of organic resources on N-mineralisation patterns to be simulated in accordance with observed responses, especially during periods immediately following manure application.

Modifying and testing APSIM's phosphorus routines

The SoilP and modified maize modules that existed when the project commenced explored the feasibility that it might be possible to include P-stress as a limitation to growth in APSIM crop models. During this project, as it became clear that that was indeed feasible, two significant advances were made.

Firstly, the P status of the crop had been considered only on a whole plant basis. This is not consistent with how N is modelled in the APSIM crop modules; in particular, it is far from ideal when a sequence of crops is to be simulated (for example, how to handle P in residues at harvest?). The development was to simulate the partitioning of P to different plant components (leaf, stem, flower, grain, root) throughout the life of the crop. A consequence of this development is that the data requirements for specifying the P dynamics in the crop are much greater, because P concentrations in the various plant components need to be described. A new parameter set (specifying P concentrations and stresses) was created for maize (based on results from an earlier experiment at Katumani — ACIAR Project no. 8326).

The second improvement was in the P-uptake routine. In the prototype, this was directly related to the amount of labile P in a soil layer. Current understanding suggests it ought to be related to the P concentration in solution at the root interface. A new routine was introduced into the code and 'tuned' to the Katumani experiment. Testing against other data sets (particularly that from Maseno on a very different soil with much higher P sorption characteristics, and from Machang'a) showed that the new uptake routine and parameter set was transferable. Having shown that the model could simulate P-deficient maize, the P routines were put into an APSIM crop template so that, in principle, any model using the template can be P-aware, provided the necessary parameter set exists to define P concentration in the plant and the effects of P stress on the plant growth processes.

The initialisation of the APSIM SoilP module requires inputs for labile P and P sorption on a soil layer basis. In this project, labile P has been identified with bicarbonate extractable P (Olsen P), though further testing on a wider range of soils is needed. It is unlikely that there is a 1:1 fit between the conceptual labile P of the model and any soil P test. The measure of 'P sorption' used is the amount of P sorbed at 0.2 mg L^{-1}.

For model-testing purposes, the only additional crop variables beyond those needed to validate the N and water routines would be P concentrations in plant components and P uptake. The parameter set required to make a crop model 'P-aware' comprises values for the maximum, minimum and senesced P concentration in the different plant components through the growth cycle of the crop, together with factors specifying how P stress affects photosynthesis, leaf expansion and phenology.

Unfortunately, during the project, no data set from Latin America, Africa or Asia contained all the required data to thoroughly evaluate the model. Ideally, for testing the ability of the SoilP module to simulate effects of P on crop growth, one would want to look at crop growth (yields, phenology, leaf area, nutrient uptake), soil water and rooting depth, mineral N in soil, soil P test values and, in a long-term experiment, soil organic matter. To address this, ongoing fieldwork in Latin America will be used for further testing of the model.

None of the data sets explicitly addressed the effectiveness of P in organic sources. In the model, mineralisation of P is simulated in a similar manner to N and will be determined by the C:P ratios of the substrate and the soil organic matter being synthesised. Using typical values for C:P in soil microbial biomass of 10–35, leads to the inference that net P mineralisation from an organic source would require a C:P of less than 100 (i.e. a P concentration of greater than 0.4% in tissue). This does not conform with published data. The cause of the disparity is again thought to lie in the C:P ratio not remaining constant during decomposition. For P, the water-soluble fraction has a much lower C:P ratio than the total C:P. Therefore, in the enhanced SoilP module the release of plant-available P from organic inputs depends on the FPools having different C:P ratios.

Testing of APSIM with long-term tropical data sets

Long-term experiments covering a range of soil types were identified by project collaborators in East and West Africa, Latin America, and Southeast Asia, and were used to test the new APSIM modules for predicting nutrient release and plant growth under field conditions. Results show that the model performed well across a wide range of applications, from simulation of N and P supply to crops where P constraints were more severe than N, to long-term P and C dynamics, and for crop responses to different rates and qualities of manures, responses to inorganic and manure combinations, and residual benefits of manure.

Using the long-term data for the Machang'a experiment, the model was shown to accurately predict crop responses to inputs of manure or fertiliser, while the predicted dynamics of labile P in soil were similar to the measured Olsen P data. Of course, none of these simulations was perfect, and discrepancies between observed and predicted data were reported. Notably for the Maseno data set, where soil P was determined irregularly (and soon after fertiliser application), the agreement between observed and predicted values was poor. In some cases, the lack of fit between model and observed data will arise from limitations in the modelling capability, e.g. there are effects of manures other than N and P that cannot be modelled. In other cases, the discrepancies are due to our poor understanding of the observed responses, which limits our interpretation.

Generally, experiments, especially long-term ones, are not established with model validation or development in mind. This project used existing long-term experiments from East and West Africa, Latin America, and Southeast Asia and, of course, found some shortcomings in the available data. While this did not hamper model development, it has prevented the evaluation of model performance from being as thorough as one might like. Accordingly, new experimentation was established during this project in Latin America, to overcome these data constraints and for further testing of APSIM.

Extension to other crops

The 'P-aware' maize model was a major breakthrough in our thinking of how to explicitly reflect soil P dynamics and especially P limitations in crop simulations. There is a clear need to apply the new capability to other crops. During this project, fieldwork was initiated to conduct experiments that would permit parameter sets to be assembled. This work was co-funded from other projects. The crops being studied are cowpea and millet (funded by IFDC in West Africa), pigeonpea, groundnut and sorghum (funded by DFID and ICRISAT in India), and canola (funded by CSIRO in Australia).

Many of the soils in Africa and Latin America are P-fixing and/or P deficient, and these projects are now contributing further modelling capability for P dynamics in these farming systems. The SoilP module developed and evaluated within this project has provided the opportunity for these other projects to proceed, and this is a major outcome and one measure of the project's success.

Future Activities Needed in Developing APSIM

The ACIAR-funded project LWR2/1999/03 developed a unique capability in simulation modelling by introducing the ability to have crops respond to P constraints and to model N and P dynamics following addition of manures of different quality. There remains a need to test these routines against a wider suite of data sets, especially for a wider range of cropping systems and soil types.

The external review team made several recommendations about follow-up activities with project partners. In the short and medium terms, these were to:

1. generate a few high-quality contrasting data sets for validation
2. refine and publish the data collection protocols for others to use
3. start working with end users including farmers to utilise model outputs.

A two-year project extension has since been funded by ACIAR to address the first two recommendations and, at the same time, strengthen the skills of current APSIM users in the project. The major components of this extension are as follows:

1. The N and P capabilities of the APSIM Manure and SoilP modules are being further tested against existing data sets in Latin America and Southeast Asia. Field studies established during the project were designed to provide a comprehensive data set for testing of the SoilP module and the P routines in the maize module. These studies are still in progress.
2. As part of the testing activities above, researchers from Latin America and Southeast Asia would be exposed to the use of the APSIM model and how it might be applied in the carrying out of their research activities and in extending, to the farming community, the results of their research. Training in the use of APSIM for the partners would be a component of this activity.
3. The data collection protocols for manure characterisation are being refined and published, so future researchers collect data that are appropriate to Manure module use. Also, the minimum data set protocols for APSIM are being updated.