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Use of mass balance to test and improve system models: Case study with APSIM

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Abstract: Mass balance can be a useful tool to understand both a model and system being modelled. In this presentation we discuss the benefits their use to assess the performance of agricultural system models. To illustrate this, the APSIM framework simulated a New Zealand irrigated, grazed pasture system under steady-state. Mass balances for water, carbon, and nitrogen were constructed, including all internal transformations. We show these can provide invaluable insights into the impact model structure, and parameter initialisation, have on system behaviour. Although constructing comprehensive mass balances may not be trivial for complex model frameworks, it is a crucial task for testing and improving them. We advocate for the provision of tools to facilitate this task.

Keywords: *Systems modelling, mass balance diagram, model testing*

1. INTRODUCTION

Mass balance is a fundamental principle in systems modelling that ensures the conservation of mass within a defined system boundary. In agricultural systems modelling, the basic form involves tracking all inputs entering the system (such as fertilisers, water, and organic inputs) and all outputs leaving the system (including harvested crops, livestock products, and emissions to air and water). However, including transformations occurring within the system (e.g. nutrient cycling), tracking the inputs and outputs to each pool, is crucial for a more complete and meaningful analysis.

As a simplified representation of real systems, agricultural system models contain unavoidable uncertainties. While these can be minimised through extensive testing and validation against a wide range of experimental data (Wang et al. 2020), it is unfeasible to concurrently measure all inputs, outputs, and transformations. Mass balances not only ensure physical consistency across model components but also enables the quantification of fluxes that cannot be, or were not, measured directly and provides valuable insights into system behaviour. This is especially important in long term simulations where, without sensibility checking, uncertainties in model assumptions can become amplified. The magnitude of fluxes can also indicate the importance of specific processes within a system. Graphical representation of system-level mass balances can be very useful for comparing different model structures, identifying differences in modelling approach. These visualisations can also be valuable for assessing whether a modelling tool is appropriate and has the necessary complexity for a given task.

In most process-based agricultural systems model frameworks, the construction of a mass balance quantifies the fluxes of water and elements, such as carbon (C), and nitrogen (N). Generally, given the complexity of such frameworks, this task is not trivial for non-experts, particularly for fluxes describing internal cycling. Therefore, comprehensive mass balances are seldom built or reported by users or developers, limiting model exploration. Here we present the construction of mass balances for water, C, and N using the Agricultural Production Systems Simulator framework (APSIM – Holzworth et al. 2018) simulating a pasture system in New Zealand (NZ). We use this to illustrate insights into the impact that mechanisms and assumptions within models had on system behaviour and the emergent properties of the model framework. We also highlight the need for tools to facilitate this task.

2. METHODS AND RESULTS

Within the APSIM Next Generation framework (www.apsim.info), the specific models used were AgPasture, SoilWater, SurfaceOrganicMatter and Nutrient, alongside manager scripts performing management actions (e.g. defoliation and irrigation). The framework was set up to mimic management actions of a low-input, irrigated pasture, rotationally grazed by sheep in Lincoln, Canterbury, NZ. The soil was a moderately-drained silt loam with a sandy subsoil. APSIM's WeatherSampler was employed to de-trend and extend the local weather data. Spin-ups were used to ensure that pools within the system were under steady-state. The simulation was then run for 1000 years, and comprehensive mass balances for C, N and water pools were constructed. Scripts were used to estimate some fluxes as outputs were not readily available. Graphical representations are shown in Figure 1.

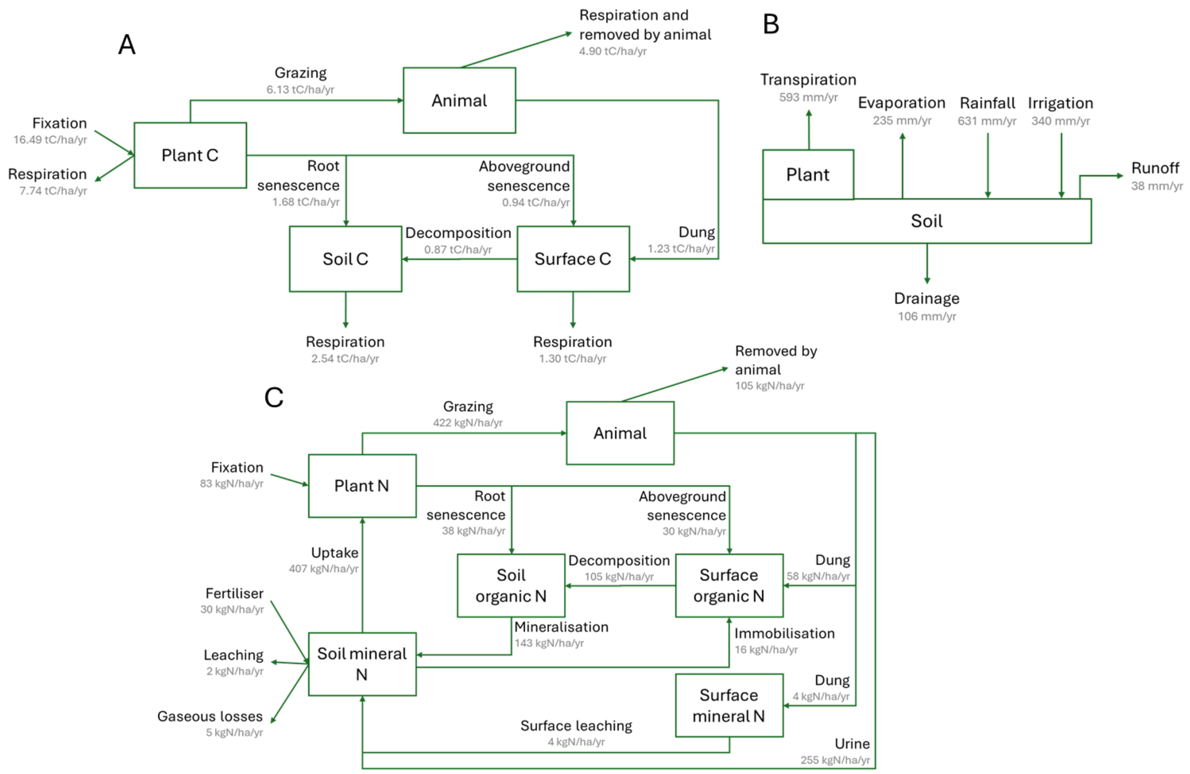

Figure 1 Mean annual carbon (A), water (B) and nitrogen (C) fluxes in a long-term simulation of a low-input, irrigated pasture, rotationally grazed by sheep in Lincoln, Canterbury, NZ

It is apparent that nitrogen has the greatest number of primary pools and fluxes (Figure 1C), reflecting the natural complexity of the N cycle and forms in which N occurs (Verburg et al. 2025). N flux values suggest internal cycling is four times greater annually than exports or inputs to the system, with the majority bypassing the soil/surface organic pools. Similarly, Figure 1A shows that the greatest loss of C from net primary productivity is through the animal. Figure 1C also highlights the decoupling of surface mineral N from surface organic N. Although out of scope here, values in Figure 1 could be used to test sensibility by comparing with measured values.

3. CONCLUSIONS

Mass balances are fundamental in systems modelling yet seem underutilised. Graphical displays of balances are useful tools to illustrate how model pools within a framework are organised and to summarise results holistically. As such, they can provide insights into the impact that mechanisms and assumptions within the model have on system behaviour and emergent properties. They can be used to compare different models, identify shortcomings, and make decisions on appropriateness of a model to a given task.

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