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Modelling greenhouse gas emissions in mixed crop–livestock farming systems

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Abstract: The farming sector is pivotal in climate change mitigation, both by reducing greenhouse gas (GHG) emissions and, crucially, by sequestering atmospheric carbon. Mixed crop–livestock (MCL) systems are central to this effort, as their spatiotemporal integration can foster synergistic resource transfers across system boundaries. This integration has the potential to enhance nutrient cycling, conserves resource, improves soil quality, increases biodiversity, and promotes circularity within farming systems.

Despite their mitigation potential, MCL systems involve trade-offs that may offset their benefits. For instance, perennial pasture phases can improve soil carbon and nitrogen (via legume fixation), but these are typically grazed by ruminants (beef and sheep) which can lead to GHG emissions. The effect of these animals on GHG emissions is complex because although their dung and urine return nutrients to the soil, reducing synthetic fertiliser requirements (as can nitrogen fixation from legumes), the presence of animal's results in GHG emissions from enteric CH_4 and N_2O and NH_3 from dung and urine. Furthermore, high stocking rates and continuous grazing can overutilize pasture, reducing plant cover and increasing soil exposure, which accelerates soil organic carbon (SOC) loss through oxidation, runoff, and erosion. Using crop residues as fodder may help bridge feed gaps and reduce off-farm emissions from purchased feed, but feeding residues often increases enteric CH_4 emissions due to their poor quality. Leaving residues in the field replenishes nutrients and improves SOC. Livestock grazing on dual-purpose crops reduces supplementary feed needs but may lower grain yield and alter carbon allocation to roots, root growth, and soil properties. Overall, MCL systems are complex and heterogeneous, with significant spatial and temporal variability driven by interactions among soil, climate, crops, and livestock. All the GHG fluxes in crop and pasture phases carry over into MCL systems, but MCL systems introduce additional feedback loops, and these feedback loops are further overlain by additional spatial and temporal interactions with the allocation of land between crop and livestock enterprises, or the sharing of land at certain times in the year.
Simulation models are increasingly used to assess system-level changes and whole-farm co-benefits and trade-offs. However, not much attention has been paid to their application in understanding multifunctionality and complex interactions in MCL systems, especially for estimating whole-farm GHG balances. Models capable of predicting major GHG fluxes in MCL systems must integrate sufficient physical, chemical, and biological process detail to capture interactions among climate, soil, plants, and animals.

We analysed six process-based models (APSIM, DayCent, DNDC, FASSET, IFSM, and PaSim) from around the world to compare their capacity to predict GHG emissions by representing key drivers and processes in MCL systems. Most models captured key drivers and processes related to climate, soil, crop/pasture, livestock systems, and their interactions, either directly or indirectly, with APSIM and IFSM capturing the greatest number of these drivers and processes. No model explicitly represents the processes of soil microbial community dynamics, animal health and productivity, residue burning, or soil acidification in the context of GHG emissions dynamics. Nevertheless, the conceptual approaches to modelling principal GHG emissions, the level of input detail, vegetation and livestock diversity, and management practices vary substantially across models. These findings highlight the need for further development and harmonization of process-based models to enhance their accuracy and applicability for GHG emissions assessment in mixed crop-livestock systems.

Keywords: *Mixed-farming, Greenhouse gas, process-based models, APSIM*

