Croplands Research Group Greenhouse Gas Mitigation Summary 2016-01

Potential mitigation of greenhouse gas (GHG) emissions and adaptation to climate change with integrated crop-livestock systems (ICLS)

GLOBAL RESEARCH ALLIANCE
ON AGRICULTURAL GREENHOUSE GASES

What is the issue?

Agriculture is a source for three primary GHGs – carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) – but agriculture can also be a sink for CO_2 through C sequestration into biomass products and soil organic matter (Johnson et al., 2007).

A growing awareness is emerging that the stability and resiliency of agricultural landscapes appear to be impaired by enterprise specialization, concentration of operations, and expansion of scale, which have spatially and temporally compartmentalized and disrupted energy and nutrient cycles in a manner far removed from natural ecosystem cycling (Gates, 2003). Reduction of crop diversity within landscape mosaics and within crop rotations due to the disappearance of forage crops and grass-land areas reduces the potential attainment of ecosystem services traditionally served by diversified ICLS, such as improving soil structure, water infiltration, nutrient cycling, soil organic C sequestration, and soil biological diversity; and controlling weed communities, insects, and disease populations (Franzluebbers et al., 2011). Greater integration of crop and livestock enterprises may impart major benefits to the environment and to development of a sustainable agricultural production system by (Franzluebbers, 2007):

(a) more efficiently utilizing natural resources,
(b) exploiting natural pest control processes,
(c) reducing nutrient concentration and consequent environmental risk, and
(d) improving soil structure and productivity.

However, robust data to generalize responses from this contrast in farming styles remain to be collected from a variety of regions around the world.

Ruminant livestock must be considered an important part of an integrated approach, because ruminants convert cellulosic feedstuffs from traditional pastures and crop residues into high-value meat and milk products. A variety of unknowns about integrated crop–livestock systems need to be addressed:

(a) large volume of information needed for sophisticated production systems,
(b) absence of infrastructure,
(c) lack of information on how chemical usage could affect crop, animal, and human health, as well as food safety,
(d) desire to balance year-round forage supplies and labor for crop and livestock requirements, and
(e) need to develop a market for alternative meat production (consumer preference for grain-fed vs. pasture-fed beef may be changing).

An obligation to increase agricultural production across the world for food security appears to be at odds with the urgency to reduce agriculture's negative environmental impacts – partly due to loss of diversity within agricultural systems at field, farm and landscape scales (Lemaire et al., 2014). To increase diversity, local integration of cropping with livestock systems is suggested, which would allow:

(a) better regulation of biogeochemical cycles and decreased environmental fluxes to the atmosphere and hydrosphere through spatial and temporal interactions among different land-use systems,
(b) more diversified and structured landscape mosaic that would favor diverse habitats and trophic networks, and
(c) greater flexibility of the whole system to cope with potential socio-economic and climate change induced hazards and crises.

What are factors controlling GHG responses?

Integrated crop-livestock systems rely on forages as part of the diversity of crop choices. Perennial forages often extend the growing season compared with annual crops, thereby photosynthesizing, depositing rhizosphere C inputs, and drying soil during longer periods of time than annual crops (Franzluebbers, 2014). Annual forages can be no-till planted and perennial forages remain without soil disturbance for several years. Lack of soil disturbance is a key factor in enhancing soil organic C accumulation rather than simply maintaining it. Soil organic C accumulation means that less C enters the atmosphere as CO_2.

N_2O emission from soil is controlled by inorganic N availability, limited oxygen (O_2) in soil, and a supply of bio-available C. High soil nitrate, compacted soil, and waterlogged conditions are often found associated with pulses of N_2O (Liebig et al., 2012). However, N_2O emissions are not only a result of denitrification (anaerobic conditions), but also nitrification (aerobic conditions). Low O_2 concentration in soil is often from water-logged or saturated conditions, but also can be a result of very high soil microbial activity that consumes O_2 and releases CO_2.

CH_4 emission from soil could occur under saturated conditions, e.g. with paddy rice in rotation with other crops, as well as with pastures that are temporarily saturated from rainfall or irrigation. Methane will also be emitted from ruminant animals in an ICLS and possibly from manure pats on grazed pasture. Anaerobic conditions are generally prerequisite for significant CH_4 emission. Pastures with elevated surface soil organic C may be a sink for some CH_4 (Liebig et al., 2010).

What are expected responses in GHG emissions?

Integrated crop-livestock systems rely on forages as part of a diversity of crop choices. These forages provide large benefit towards the balance of C in soil. Forages have extensive, fibrous root systems that explore large volumes of soil, mostly in the surface 30 cm like most crops, but also penetrating deep into the profile with many perennial grasses. Perennial forages also extend the growing season compared with annual cash crops, thereby photosynthesizing, depositing rhizosphere C inputs, and drying soil during longer periods of time than annual crops. It is this extended growth period, whether from perennial forages or cover cropping with annual forages following cash crops that likely contributes greatly to soil C sequestration. Another key factor is that annual forages can be no-till planted and harvested and perennial forages remain without soil disturbance for several years. Lack of soil disturbance may be vital for integrated crop-livestock systems to enhance soil organic C accumulation rather than simply to maintain it.

In the long-term Morrow Plots in Indiana USA, high soil organic C was maintained only in a diverse crop rotation that included ley pasture compared with continuous cropping (Nafziger and Dunker, 2011). Soil organic C was always greater under a 3-year rotation of corn-oat/clover-hay than under monoculture corn (average of 25 *vs* 17 g C kg^{-1} soil). High soil organic C was positively related with achievement of greater corn grain yield over the lifetime of this study, initiated in 1876.

A couple of long-term experiments on pasture-crop rotations in Argentina and Uruguay have also shown the value of perennial forages in maintaining soil organic C. With conventional tillage cropping in Argentina, soil organic C concentration progressively declined with continuous, annual cropping following termination of perennial pasture (Studdert et al., 1997). Using a 6-year crop + 2-year pasture rotation, soil organic C also declined with time, but pasture phases were able to rebuild soil organic C for a short time. Using a 4-year crop + 4-year pasture rotation, soil organic oscillated C with peaks at the end of pasture phase and troughs at the end of the cropping phase and no temporal trend of decline over the long term. Conclusions were that 3-4 years of pasture were able to restore soil organic C to a sustainable level if cropping was <7 years.

An experiment initiated in 1964 at La Estanzuela, Uruguay showed that continuous cropping with no fertilizer caused gradual and steady decline in soil organic C (Garcia-Prechac et al., 2004). Application of fertilizer enhanced plant growth and return of residues to slow soil organic C decline, but only crop-pasture systems with at least 2 years of perennial pasture in the rotation allowed soil organic C to stay at the initial level of soil organic C (Morón and Sawchik, 2002). Rotation with 3 years of cropping and 3 years of pasture was more beneficial on soil organic C concentration than 4 years of cropping and 2 years of pasture. Further research will determine long-term effects and a switch to no-tillage management.

Rapid soil organic C accumulation with establishment of forages has also been documented in the southeastern USA. With bermudagrass establishment, soil organic C accumulation during the first 5 years was dependent on type of management, i.e. rate of accumulation was 1.40 Mg C ha^{-1} yr^{-1} when grazed by cattle, 0.65 Mg C ha^{-1} yr^{-1} when unharvested, and 0.29 Mg C ha^{-1} yr^{-1} when hay was removed (Franzluebbers et al., 2001). With tall fescue establishment, soil organic C accumulation during the first 8 years of management was 1.36 Mg C ha^{-1} yr^{-1} when grazed by cattle and 0.69 Mg C ha^{-1} yr^{-1} when hayed (Franzluebbers et al., 2012).

Rotation of pastures into a cropping phase often leads to decline in soil organic C, but this will depend strongly on management approach. During the first 3 years of cropping following pasture in Georgia USA, stock of soil organic C declined with conversion of long-term pasture to conventional tillage cropping at 1.2 Mg C ha^{-1} yr^{-1} compared with no tillage cropping (Franzluebbers and Stuedemann, 2008). Soil organic C under no tillage cropping at the end of 3 years was similar to that of continuation of perennial pasture. In Nebraska USA, soil organic C was maintained at 90 Mg C ha^{-1} at a depth of 0-30 cm during 6 years of no-tillage corn production following chemical termination of bromegrass sod (Follett et al., 2009). Therefore, conservation tillage systems combined with crop-pasture rotations may offer an important opportunity to further improve agricultural soils by avoiding losses of soil organic C associated with cropping, but also by including high-biomass forage crops (above- and below-ground) and cash crops in the rotation to possibly enhance soil organic C levels beyond levels obtained in long-term pastures. This might be possible, since opportunities for high soil fertility input with animal manures on cash-crop responsive annual crops can promote deep and robust rooting different from that of perennial crops and significant soluble C and N inputs might enhance aggregation and soil biological diversity to promote sequestration of C.

Several recent research experiments have focused on grazing of cover crops in integrated crop-livestock systems in Brazil (Carvalho et al., 2010). After 10 years of winter grazing of cover crops rotated with summer soybean production, soil organic C and various soil C fractions were greater at moderate grazing intensity (20 to 40 cm sward height) than at lower and higher extremes (da Silva et al., 2014).

Impact of ICLS on CH_4 and N_2O emissions is complicated by the multitude of competing properties affecting production and consumption of CH_4 and N_2O (e.g. methanogenesis, methanotrophy, nitrification, and denitrification). Ammonium accumulation in soil can suppress CH_4 consumption but increase nitrification activity, whereas soluble C accumulation and low O_2 concentration in soil (either through compacted soil or from high heterotrophic activity) can promote production of both CH_4 and N_2O. Both net CH_4 emission and uptake were observed during different periods of the year in an evaluation of different long-term no tillage cropping systems in southern Brazil (Bayer et al., 2012). Greatest variation in CH_4 flux was observed after cover crop termination in the spring, when flux was related to ammonium and dissolved organic C concentrations in soil. Manure application to soil will often increase soluble C, provide abundant and readily available ammonium, and lead to O_2 depletion due to large retention of water in soil and/or promotion of high soil heterotrophic activity – all prerequisites for N_2O emission (Petersen et al., 2006; Webb et al., 2010). Soil N_2O emission was greater with grazing of N-fertilized winter cover crop in Brazil than without grazing and no fertilization, partly attributable to differences in availability of N, but also to potential animal traffic (Piva et al., 2014). Ammonium and nitrate concentrations were factors strongly associated with peaks of N_2O emission from urine and dung about 3 weeks after deposition (Sordi et al., 2014).

From a meta-analysis across a diversity of studies in eastern Canada, N_2O emissions were greater following annual crops that were incorporated by tillage in the fall (2.4 kg N_2O-N ha^{-1}) and not incorporated (1.2 kg N_2O-N ha^{-1}) than following perennial crops that were not incorporated (0.3 kg N_2O-N ha^{-1}) (Gregorich et al., 2005). Emissions were also greater following annual crops than following perennial crops whether unfertilized (1.5 vs 0.2 kg N_2O-N ha^{-1}) or fertilized (2.8 vs 0.6 kg N_2O-N ha^{-1}).

How can research help in refining GHG mitigation estimates?

To characterize and analyze how integrated agricultural systems can become more sustainable, four basic categories need to be considered (Hanson and Franzluebbers, 2008): (1) social/political, (2) economic, (3) environmental, and (4) technological. Multi-disciplinary research needs to be conducted in different ecological regions of the world; biophysical and social issues need to be addressed to be able to develop robust interpretations of how systems affect GHG emissions and how agricultural systems can be modified to overcome changing climate.

Synthesis / recommendations

A diversity of integrated crop-livestock systems (ICLS) exist, so specific responses to climate change will likely be diverse. Systems having a perennial forage component are likely to lead to an increase is soil organic C sequestration, a process that can improve soil quality and the resilience of a cropping system against climate perturbations to crop growth and yield. Forages offer an opportunity for grazing livestock to utilize high-quality cellulosic feedstuffs – an agronomic product not otherwise competing with human food production. In addition, livestock transformation of feedstuffs through processing in the rumen can lead to enhanced nutrient cycling and efficient resource utilization on the farm scale. Important opportunities in ICLS exist to distribute animal manures spatially on the farm naturally through dung deposition with grazing and through mechanical distribution of manure from concentrated feeding locations to nutrient-poor areas or environmentally sensitive areas elsewhere on the farm.

Although ruminant animals emit CH_4, quantity of emission may be roughly the same per animal whether in feedlot or on pasture. Age of animal prior to slaughter is a key factor in total CH_4 emission per product – older animals emit more CH_4. N_2O emission is likely reduced in pasture-based systems compared with feedlot-based systems due to lower intensity of manure deposition on a much larger landscape area. Reduction in N fertilizer for crops in rotation with forages and with application of manure will reduce N_2O emissions. The large gain in soil organic C with establishment and maintenance of perennial pastures is a key mitigation strategy offered by ICLS, but is also a key adaptation strategy to overcome drought and partially control flooding by improving soil quality, when forages are appropriately distributed across a landscape scale. Diverse farming operations in ICLS reduce overall risk of failure, despite any one component being negatively affected as in specialized agricultural systems. Diversity also offers resilience of farming system against perturbations caused by extreme weather events and climate change.

Network collaborators

Lindsay Bell, CSIRO, Brisbane, Australia
Klaus Butterbach-Bahl, Karlsruhe Inst. Technol., Germany
Paulo Carvalho, Federal University of Rio Grande do Sul, Brazil
Pierre Cellier, INRA, Grignon, France
Juan Cruz Colazo, INTA, Villa Mercedes, Argentina
Martin Chantigny, Agriculture and Agri-Food Canada, Quebec QC
Carlos Crusciol, São Paulo State University, Botucatu, Brazil
Jeferson Dieckow, Federal University of Parana, Curitiba, Brazil
Alan Franzluebbers, USDA-ARS, Raleigh, NC, USA
April Leytem, USDA-ARS, Kimberly, ID, USA
Yong Li, Chinese Academy of Sciences, Changsha, China
Mark Liebig, USDA-ARS, Mandan, ND, USA
Lutz Merbold, ILRI, Nairobi, Kenya
Sheilah Nolan, Alberta Agric. Rural Develop., Edmonton, Canada
Cristiano Pariz, São Paulo St. Univ., Botucatu, Brazil

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Jonatas Thiago Piva, Jeferson Dieckow, Cimélio Bayer, Josiléia Acordi Zanatta, Anibal de Moraes, Michely Tomazi, Volnei Pauletti, Gabriel Barth, Marisa de Cassia Piccolo

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