Nutr Cycl Agroecosyst (2022) 123:1–4
https://doi.org/10.1007/s10705-022-10215-3

EDITORIAL

Developing climate-resilient agri-environmental production systems

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Received: 9 June 2022 / Accepted: 9 June 2022 / Published online: 23 June 2022

The demand for food, fibre, and raw materials from an ever-decreasing amount of land is increasing the environmental footprint of agricultural production systems and is a drain on a dwindling reservoir of essential resources. This is resulting in the increased emissions of greenhouse gases (GHGs), and air pollutants, including ammonia and nitrogen oxides, as well as nutrient leaching, eutrophication, and biodiversity loss. Of the three major GHGs, agriculture is unique in that it is the major source of two of these, methane (CH_4) and nitrous oxide (N_2O). Globally, crop and livestock production account for more than 50% of CH_4 emissions and 75% of N_2O emissions (FAO 2020). Of these, agricultural soils emit over 4% and livestock and manure management approximately 6% of global GHG emissions (FAO 2020). Food production itself accounts for 20–40% of total global anthropogenic GHG emissions if all pre- and post-production processes are considered (Francesco et al., 2021). Agriculture and associated land use activities also represent approximately 20% of all economic activities (Francesco et al., 2021), and are a major contributor to climate change.

Whilst the large GHG emissions from agricultural production systems highlight their negative impact on the environment, they also draw attention to the potential for significant mitigation actions. This is in fact one of the many conundrums associated with agricultural production systems, that they are both a major contributor to climate change, through enhanced GHG emissions, but also offer significant opportunities for reducing GHG emissions. Agricultural soils, for instance, are generally low in carbon (C) but have the potential to store large amounts of C. However, the factors that control C sequestration in soils are still not clear enough to identify the most appropriate technologies that might be used to realise the maximum climate change mitigation benefits. Alternatives to inorganic fertilizers or their more efficient use, as well as the development of improved crop varieties with a reduced reliance on nitrogen (N), could also significantly reduce N_2O emissions. Improved manure management and modifications in livestock diets can also contribute to a reduction in CH_4 emissions. Although often given a negative press, livestock could play a more central role in modern agricultural production systems. The better integration of livestock into farming systems, where they can have a pivotal role in the recycling of wastes and provide crop nutrients could contribute to a reduction in our reliance on inorganic fertilizers. The integration of livestock with more diversified cropping systems would also contribute to improvements in on-farm biodiversity, sustainability, and circularity. The challenge is how to do this without compromising the

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productivity, economic viability, and environmental footprint of agroecosystems.

As well as being a major contributor to climate change, agriculture is also likely to be significantly impacted by climate change. The most recent FAO report on the state of food and agriculture (FAO 2021) paints a grim picture, where increases in temperature and alterations in precipitation could have wide ranging effects on crop productivity, nutritional security, and health. Of particular concern is the likely disproportionate effects of shorter-term extreme climatic events. But is it all doom and gloom? Whilst some of the negative impacts of climate change on agricultural systems are likely unavoidable, appropriate investments may enable us to adapt them to the new conditions, increasing their productivity, resilience, and resource-use efficiency (Sulser et al. 2021). This will not be without any costs, however, and planning for an uncertain future will require the development of innovative agricultural technologies and practices that can be applied across a broad range of environments and adapted to local/regional conditions. There also needs to be a willingness to make the required investment in money and resources.

There is also still a lot we do not know about the impact of climate change on crops and cropping systems and the land area that might be available for agriculture in the future. Increasing temperatures could facilitate a poleward shift in agricultural production systems to areas that are currently unsuitable. Conventional breeding programmes or new genetic technologies have the potential to be used to develop climate change resilient crops. Although rising atmospheric CO_2 concentrations are the major cause of global warming, there is evidence that this might be used to our benefit, enhancing crop productivity, and offsetting the effects of increased temperatures or water deficits (Yiotis et al. 2021; Ziska 2021).

It is against this background that the CRAES group, the acronym standing for Climate-Resilient Agri-Environmental Systems, was formed in 2020. This recognised the importance of developing agricultural systems that were both resistant to climate change and had a low environmental footprint. To address the multifaceted challenges associated with the development of new climate-resilient and environmentally compatible production systems would also require a multidisciplinary, systems-based approach. The first conference associated with this group, ISCRAES 2020 (https://www.iscraes.org/iscraes-2020/) was held virtually in 2020 with the intention of making this a biannual event. The next meeting (ISCRAES 2022) will be held in Dublin in August 2022. This special issue represents a selection of the presentations made at the 2020 symposium.

Rice is a staple food for more than 50% of the global population with China and India accounting for around 50% of production, with significant expansion occurring in Latin America and Africa. However, rice cultivation has a large environmental footprint and is a major source of GHGs. Consequently, much effort has been directed at improving the yield and sustainability of these production systems through improved management practices and the use of improved hybrid cultivars. Although N is often the major factor limiting rice yields its overuse does not make economic sense and can result in enhanced N_2O emissions and water pollution. Banerjee et al. (this issue) show that the environmental impacts of N applications to hybrid rice cultivation could be minimized without compromising yields by simply reducing the application rate. In India, fertilizer N applications have been increasing but the N use efficiency remains poor due, in part, to a lack of information on what the optimum requirements are for different site and environmental conditions. Clearly, there is significant scope for the improved management of N in this and other production systems, including a reduced reliance on inorganic fertilizer inputs using biologically fixed N or genetic modifications that enhance the acquisition of N from the soil.

The use of bio-stimulants in crop production has increased in recent years where they have been shown to increase yield/yield quality and stress resistance as well as reducing the reliance on external nutrient supplies. Amaranthan and Balasingham (this issue) show that the application of a cell signalling compound called Biozest (a spray composed of plant extracts, fatty acids, plant compatible organic acids and wetting agents) led to improved pasture and livestock productivity. This worked because the application of Biozest increased the sugar content of pasture grass and its digestibility by grazing animals leading to increased milk and meat production. An added benefit was the increased production of phenylpropanoids, which could contribute to greater biotic and abiotic resistance. The reduced deamination in animals feeding on grass treated with Biozest, together with a reduction in excreted urea would likely lead to lower enteric CH_4 production and soil N_2O emissions. These results show that the application of compounds that influence plant metabolism have the potential to improve the efficiency of grazing systems with a lowering of their GHG footprint.

Green manures have long been used in more traditional low input production systems and there is an increasing interest in their wider use under more intensive agricultural practices. Green manures have several potential benefits, including increased soil C sequestration, reduced nutrient leaching, and weed suppression, and as a source of essential nutrients, where the focus has often been on their ability to enrich the soil with N. Consequently, many of the green manures that have been used are comprised of biological N fixers. In addition to N, phosphorus (P) availability is also often a major growth-limiting nutrient, although the potential role of green manures in providing a source of P has received less attention even though biological N fixation is often associated with a higher tissue P concentration, due to the higher P required for symbiotic N assimilation (Stevens et al. 2019). Gao et al. (this issue) show that the addition of chopped alfalfa green manure to rice cultivation systems enhanced P uptake directly and indirectly by increasing the availability of soil P. Given concerns about the depletion of the finite global mineable deposits of P more attention needs to be directed at the use of green manures as a source of available P for crop growth and their ability to mobilize existing soil reserves.

The generally expected increase in plant productivity associated with global increases in atmospheric CO_2 and/or N deposition will also result in an increase in crop residues/litter production. The impact of increased litter fall could have several effects on the GHG budget, including an increase in labile C substrates that are required for microbial oxidation processes that lead to GHG emissions, or by acting as a barrier to gaseous diffusion and enhance soil C sequestration. Zhang et al. (this issue) show that the removal of litter from *Cinnamomum camphora* (Linn.) Presl. plantations resulted in an increase in N_2O emissions. As they indicate, however, this is inconsistent with most of the available information showing that litter removal generally reduces N_2O emissions (Zhou et al. 2022). However, in these P deficient soils the addition of P decreased N_2O emissions. It is known that forest type (Zhou et al. 2022) and litter quality (Walkiewicz et al. 2021) can also influence GHG fluxes, indicating a complex interaction among litter type/quality, soil nutrients and gaseous emissions. Adequate assessments of the effect of increased litter inputs on N_2O emissions will therefore need to take account of all these factors before we can say anything about the generality of the findings reported by Zhang et al. (this issue).

Although these papers only represent a small selection of the presentations given at the ISCRAES meeting they do address important issues relating to the potential sustainability of future agroecosystems and how these are likely to impact on the environment. Further studies are clearly required if we are to be able to develop the resilient, environmentally compatible, and sustainable production systems that will be needed to supply a global population.

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