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Editorial:Ecological intensification and sustainable intensification: increasing benefits to and reducing impacts on the environment to improve future agricultural and food systems

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Editorial on the Research Topic
Ecological intensification and sustainable intensification: increasing benefits to and reducing impacts on the environment to improve future agricultural and food systems

Sustainable agricultural systems are pivotal to future agriculture's capacity to support the projected global population of 9 billion people by 2050. Future agricultural food systems must effectively tackle pressing sustainability challenges that adversely affect both food production and the environment. These challenges encompass heightened land demand, sustainable use of synthetic nitrogen, declining soil carbon pool, and biodiversity loss. This Research Topic collection highlights different approaches to improving the environmental sustainability of agricultural systems around the world. Changes in climate require regional to farm-level approaches to climate change adaptation. From 2009 to 2018, maize production in China has been impacted by changes in climate but this is regionally dependent (Zhang et al.). Strategies to reduce agriculture's environmental impact also depend on the region evaluated and the farm or agricultural stakeholder group involved. Within this context, the concepts of sustainable intensification (SI) and ecological intensification (EI) play important roles (Figure 1). SI of agricultural systems involves more efficiently using resources in order to spare future degradation of natural habitat. Meanwhile, EI diversifies farming systems which can not only improve agricultural production, but also enhance agro-ecosystems.

Typically, SI involves specific changes to component(s) of specialized conventional agricultural systems such as encouraging water conservation, adopting low-carbon agriculture, and increasing the efficiency of inputs used on-farm. Water conserving irrigation adoption in drier agricultural regions such as Iran's Fars province with networks of reservoir and canals was low among surveyed farmers (37%), but could be improved by reducing the interest rate paid for such capital investments from the current 18%–8% (Mirzaei et al.). Low-carbon agriculture adoption potential is influenced by regional support networks. Central and western regions in China, which are more rural and less connected to other regions, require more support than eastern China which has more developed networks, a more central network position relative to other regions, and more control over resources used for low-carbon agriculture (Fang et al.). The ecological efficiency of input use can be enhanced by using agricultural inputs such as nitrogen fertilizers and fungicides with less adverse environmental impacts. Use of older machinery results in higher fuel consumption and greenhouse gas emissions. Najafabadi et al. modeled such ecological efficiency increases using data envelope analysis (DEA) and the material balance principle (MBP) applied to a slacks-based measure (SBM) model for saffron production in Iran.

EI can be adopted for both settled agriculture and shifting cultivation. Zhao et al. found adoption of green agricultural technologies (e.g., physical control technology, pollution-free pesticides, soil formula fertilization, agricultural film for water conservation, water/fertilizer integration technology, grafting) for smallholder farmers relocated due to construction of the Three Gorges Reservoir are positively associated with adoption of e-commerce to market and sell agricultural products. This was based on 688 surveyed re-settlers with 37.7% adopting four or more of these six green agricultural technologies. Long-term hay and maize rotations in Vermont, USA from 2009 to 2021 analyzed by White et al. suggest that environmental goals can be balanced with maintaining adequate crop yield. In this long-term experiment, continuous corn, a short rotation (4 years hay, 6 years corn), and a long rotation (8 years hay, 2 years corn) were evaluated. Here, the short rotation did not significantly reduce corn dry matter yields. Meanwhile soil organic matter, respiration, aggregate stability, and forage crude protein increased compared to continuous corn, especially with more years of hay in the rotation. However, active carbon and forage digestibility were lower for corn-hay rotations compared to continuous corn.

Shifting agriculture (i.e., swidden) is an older method of agricultural production where small areas in the forest are burned for short-term agricultural production and after farming is abandoned, the area is reclaimed by forest as other areas are used. However, the area selected can have significant implications in reducing or increasing adverse environmental impacts. For example, in northern Thailand, lower slope for burned areas in shifting agricultural production was associated with less soil loss and more soil organic carbon and nitrogen, electrical conductivity, as well as exchangeable magnesium and calcium (Arunrat et al.). Therefore, swidden in flatter areas can improve environmental sustainability.

EI can also be used to diversify farm enterprises and to preserve high conservation value areas. Total green factor productivity can be associated with enterprise diversification such as agro-tourism. Wang et al. documented greener, circular agricultural productivity is associated with agro-tourism in China based on data from 30 province-level administrative divisions from 2008 to 2019. Preservation of high conservation value areas can use jurisdictional approaches, taking into account environmental metrics to prioritize areas for conservation. In a case study jurisdiction in Indonesia, Padmanaba et al. show greater coordination between government agencies is required at different jurisdictional spatial scales in order to define high conservation value areas outside of oil palm plantations in native forests.

The findings of these studies suggest that making informed choices when selecting tools and equipment, implementing alterations in land-use patterns, and adopting innovative management practices/processes

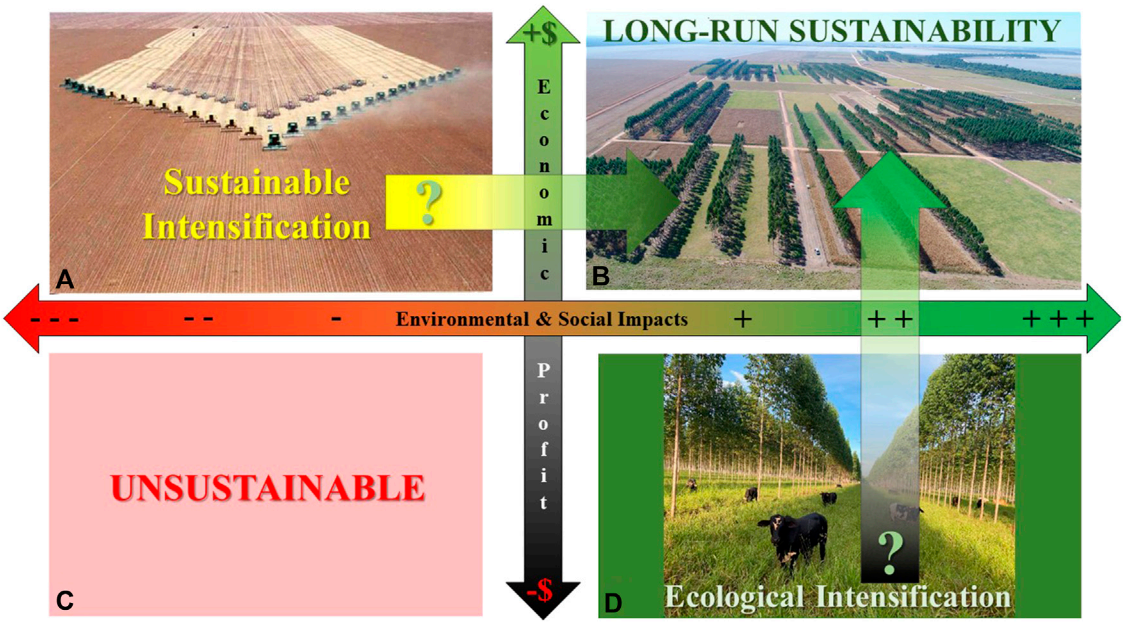

FIGURE 1
Economics versus environmental impact of **(A)** sustainable intensification pathway to **(B)** long-run sustainability, **(C)** unsustainable agricultural systems, and **(D)** ecological intensification and pathway to **(B)**. Pictures provided by Gabriel Rezende Faria, a journalist and public relations officer at Embrapa, Brazil.

that minimize environmental harm are not only feasible but also pivotal steps toward achieving collaborative, sustainable, and resilient regional food systems. Embracing EI and employing appropriate SI approaches both play a pivotal role in environmental sustainability and global food security. To ensure success, it is imperative to disseminate accurate information to stakeholders at the right stages of agricultural operations. Proactive communication is essential for reducing overuse of both natural and synthetic resources, which could otherwise lead to further detrimental environmental effects.

Additionally, effective collaboration between research organizations and government or private entities is crucial for establishing poignant guidelines, regulations, and policies that facilitate sustainable transitions. Public policies such as government subsidies can incentivize the technologies/practices showcased in this Research Topic for SI/EI enhancements. This collaborative effort is influential in achieving SI and EI strategies that can yield positive outcomes for both society and the environment, help mitigate existing negative impacts, prevent further depletion of soil organic carbon, restore ecological equilibrium, and enhance biodiversity. These practical strategies combined with public policy support can help achieve the ambitious goal of global food security by 2030.

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Conflict of interest

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