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Integrated crop–livestock systems: Strategies to achieve synergy between agricultural production and environmental quality

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ABSTRACT

A need 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. We suggest that a cause of this dichotomy is loss of diversity within agricultural systems at field, farm and landscape scales. To increase diversity, local integration of cropping with livestock systems is suggested, which would allow (i) better regulation of biogeochemical cycles and decreased environmental fluxes to the atmosphere and hydrosphere through spatial and temporal interactions among different land-use systems; (ii) a more diversified and structured landscape mosaic that would favor diverse habitats and trophic networks; and (iii) greater flexibility of the whole system to cope with potential socio-economic and climate change induced hazards and crises. The fundamental role of grasslands on the reduction of environmental fluxes to the atmosphere and hydrosphere operates through the coupling of C and N cycles within vegetation, soil organic matter and soil microbial biomass. Therefore, close association of grassland systems with cropping systems should help mitigate negative environmental impacts resulting from intensification of cropping systems and improve the quality of grasslands through periodic renovations. However, much research is needed on designing appropriate spatial and temporal interactions between these systems using contemporary technologies to achieve the greatest benefits in different agro-ecological regions. We postulate that development of modern integrated crop–livestock systems to increase food production at farm and regional levels could be achieved, while improving many ecosystem services. Integrated crop–livestock systems, therefore, could be a key form of ecological intensification needed for achieving future food security and environmental sustainability.

1. Urgency for renewing agriculture

Everywhere in the world, intensification of agricultural production has been driven by a large use of non-renewable resources that often impair environmental sustainability, as well as by a huge simplification of agricultural systems at all levels of organization, i.e. field, farm, landscape and region. Particularly in industrialized countries, agriculture has become highly specialized in response to political and economic constraints (Russelle et al., 2007; Hendrickson et al., 2008), leading to a large decline in number of farms, despite a large increase in physical and labor productivity (Hanson and Hendrickson, 2009). Intensification and specialization of agricultural systems in industrialized countries has come with increasingly negative impacts on the environment (Tilman et al., 2002), which is now considered unacceptable by society. Consequences of specialization and increasing labor productivity through simplification of crop management and greater external inputs are water contamination, sinking groundwater levels, rising atmospheric greenhouse gas concentrations, soil erosion and dysfunction, and loss of biodiversity (Franzluebbers et al., 2011). Agricultural science must now overcome this apparent contradiction between the necessity to improve productivity of agricultural systems for food security reasons and to urgently prevent degradation and restore the environment.

In developing parts of the world, agricultural systems are evolving very rapidly under demographic pressure, but are confronted by partly similar issues, albeit under unique conditions. Although labor productivity has not increased so much in the past years, because of the important population pressure on land (Paillard et al., 2011), intensive, specialized high-input systems appear to be a goal for modern farming, often in contradiction with the reality and diversity of rural systems and without any deep appreciation

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for productivity potential of local crop–livestock systems. For example, in Argentina, the cultivated area of crops increased 45% between 1990 and 2006, while use of fertilizers increased 400% (Gavier-Pizzaro et al., 2012). Consequences were loss of habitat heterogeneity, particularly loss of avian diversity and associated ecosystems services that benefit crop production. The Pampa biome in Brazil is experiencing similar threats, in which soybean production is expanding at the expense of natural pasture areas (Carvalho and Batello, 2009). This intensification process based on less diverse specialized systems has occurred not only with cash crops, but with sown pastures as well. Brazil has around 117 million hectares of sown pastures, of which 70% are of one grass genus—*Brachiaria* spp. This process has occurred mainly in the Cerrado, which now has <20% of the original vegetation. According to Zimmer et al. (2011), ~80% of pasture areas have some level of degradation, reflecting the low sustainability of non-diverse farming systems.In both industrialized and developing regions, increasing uncertainties with climate and commodity prices put into question the "specialization—higher productivity" path of development (Evans, 2009). Farmers are deeply concerned by the vulnerability of their systems, notably in developing countries without subsidies, but also more and more in industrialized countries, such as with price controls declining in Europe. Diversified systems such as crop–livestock systems appear then to be an interesting alternative and path forward for agricultural development in the face of climate change and volatility of commodity and input prices. Farming systems need to be robust to overcome hazards (Milestadt et al., 2012), therefore diversity should be a major lever of that flexibility, whether that be through activities such as crops and livestock for sale or resources such as crop, fodder, intercrop cultures, permanent grasslands, etc. (Andrieu et al., 2007).

Livestock production is strongly increasing worldwide because of the increase in demand for animal protein by people in developing countries. Greater income per capita also plays a role in demand for animal products, such as occurring with dairy products in Asia. Animals have various functions in developing countries other than for food production, such as a source of life saving, production of organic fertilizers, etc. Notably, animals have been considered a sign of wealth for the poor, because of these multiple functions (Duteurtre and Faye, 2009). Increasing size of herds is not the only trend (Bouwman et al., 2005). Due to the low energy efficiency of converting plants to animal products, it may be untenable to develop large and very specialized intensive livestock production systems in developing countries. Moreover, these highly intensive and concentrated livestock production practices are generating highly specialized and uniform land use systems, which can be the source of high concentrations of water pollution and emission of greenhouse gases, as well as greater sensitivity to climate change. However, domestic herbivores are not necessarily in competition with humans for food, since they can utilize plant material unsuitable for the human diet from grassland ecosystems located on soils/landscapes not suitable for efficient crop production (Lemaire et al., 2011). Therefore, grasslands should continue to play an important role not only as fodder for sustainable animal production, but also to provide landscape space for realizing essential ecosystem services, such as absorbing negative environmental impacts resulting from the intensification of agriculture (Lemaire et al., 2005).

Integrated crop–livestock systems could provide opportunities to capture ecological interactions among different land use systems to make agricultural ecosystems more efficient at cycling nutrients, preserving natural resources and the environment, improving soil quality, and enhancing biodiversity. Moreover, diversifying agricultural production could utilize labor more efficiently at farm and/or regional scales (Hoagland et al., 2010). Integration of crop and livestock production was the basis for enhancing agriculture in Europe in the 17th century. Eventually, intensive use of fertilizers and mechanization reduced the necessity for this integration. Competitiveness in the world market appears to be based on specialization and increasing size of farms. As a consequence, crop and livestock systems in Western Europe and North America developed more and more into separated farms, especially following rapid industrialization post World War II. Moreover these two systems developed separately in different agro-ecoregions, leading to large uniformly intensive landscapes of cereal production without livestock and concentration of livestock production facilities, such as in Brittany France and in the Netherlands.

Therefore, our challenge is not to rediscover or adopt ancestral agriculture systems that would lead unavoidably to a drastic reduction of agricultural production incompatible with increasing food security requirements, but rather to invent modern integrated systems based on available technology capable of providing both high socio-economic outputs and multiple environmental benefits (Schiere et al., 2002; Sulc and Tracy, 2007; Franzluebbers et al., 2011). This necessary coupling between crop and livestock production must be devised at all levels of organization: the field, where biogeochemical processes are operating; the farm, where management decisions are made; the landscape, where ecosystem processes and interactions between land use components are occurring; and the region or the continent, where socio-economic and political constraints are driving forces.

2. Diversity of agriculture: An antidote for intensification?

Reduction of crop diversity within landscape mosaics and within crop rotations due to the disappearance of forage crops and grassland areas reduces the potential attainment of ecosystem services traditionally served by diversified crop–livestock systems, 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). This lack of biogeochemical and ecological controls due to the loss of diversity within cropping systems has been partly compensated by the use of synthetic fertilizers and pesticides, yet which can unfortunately generate unacceptable loads of pollutants to air, water, soil, and neighboring native biotic communities. Moreover, biodiversity at a landscape level for a large range of taxa (plants, insects, small animals and birds) within intensive cereal cropping systems is highly dependent on the spatial continuity and diversity of the landscape mosaic (Bretagnolle et al., 2011a). In particular, permanent vegetation within undisturbed fields (i.e. forage and grasslands) plays an important role in landscape biodiversity by controlling meta-population dynamics (Bretagnolle et al., 2011b).

Again, our challenge in agricultural sciences is to replace the old paradigm based on simplification and standardization of production systems for optimizing productivity per unit of human labor with a new paradigm based on emphasis of diversity at field, farm and landscape scale to optimize productivity per unit of natural resource utilization through spatial and temporal interactions among landscape ecosystem components.

3. Coupling C–N cycles for reduction of environmental fluxes

In natural ecosystems such as grasslands or forests, the permanency of soil-vegetation interactions leads to strong coupling among C, N, and P. Such coupling operates: (i) in plants where N and P are linked to C by plant tissue synthesis through light interception, photosynthesis, N and P assimilation, and plant growth processes; and (ii) in soils through the dynamics of organic matter