Nutrient Cycling and Crop Responses on Integrated Crop-Livestock Systems

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Abstract
Integrated crop-livestock systems (ICLS) can bring numerous benefits to crops or livestock systems, such as increase soil C sequestration, farm profitability, and provisioning of ecosystem services. In a changing world, production systems need to become more resilient and sustainable. Specialized agriculture is characterized by a high level of inputs and outputs, and oftentimes specialize in a single crop to simplify management. However, such operational systems stray away from sustainable standards. Furthermore, specialized cropping systems may face problems such as persistence of pests and diseases, loss of biodiversity, stagnant yields, development of herbicide-resistant weeds, soil erosion and consequently loss of soil organic matter. Recombining crops and livestock in a broad and complementary system is to look back into the past to adopt a practice that used to be common centuries ago. With the advancement of technology and better understanding of this management practice, ICLS appear as an option to provide ecosystem services from agricultural lands, while potentially increasing crop production. Such systems have shown benefits as increasing in soil organic matter, increase in biodiversity, and nutrient cycling. There is an array of ICLS, which may include short and long grazing cycles, more than one animal category, crops from many different functional groups, and trees. Here, we will discuss some of the aspects in nutrient cycling and crop responses on ICLS, giving examples to call attention to some of the advantages ICLS can provide.

Introduction

As world population increases, food demand does too. Agricultural systems are now more pressured to produce in a less environmentally impactful way. Increasing productivity is a major goal but achieving it in a sustainable way is the biggest challenge we face (Duarte et al., 2020). Food production in the twenty first century is characterized by improving its productivity at the cost of high inputs requirements (Duru & Therond, 2014). Integrated crop-livestock systems (ICLS) can play a major role as a sustainable management practice on enhancing productivity, profitability, soil health and nutrient recycling by increasing nutrient dynamics transfers amongst ICLS components (Thorne & Tanner, 2002). The plant-livestock association can play a central role on ensuring adequate productive conditions for future cropping systems with the addition of reducing environmental impacts (Duarte et al., 2020).

By implementing sustainable agriculture practices such as ICLS, intensification and increased productivity can be achieved. The addition of animals or crops to conventional agroecosystems aims to provide multidirectional benefits by exploiting plant-soil-animal-atmosphere interactions (Moraes et al., 2014). Production systems that seek the integration of different associations are viable conservation practices that in the long term reduce the environmental impact and improve sustainability in comparison to conventional cropping systems (Franzluebbers, 2007). Enhanced nutrient cycling through animal excreta and urine because of their higher nutrient availability for plants in comparison to litter can play a major role on improving soil fertility and productivity and therefore enhancing plant growth and crop yield (Dubeux et al. 2009).

Multiple ecosystem services are provided by ICLS, each of its components work as entry points and modulators for individual nutrients affecting their dynamic in the diverse pools of an agroecosystem (Thorne & Tanner, 2002). This review aims to discuss some of the aspects in nutrient cycling and crop responses in ICLS.

Nutrient Cycling

Adding animals into cropping systems can increase nutrient cycling. Grazing animals remove nutrients from soil by ingesting forage plants. However, most of the ingested nutrients cycle back to the soil via excreta deposition; ungrazed forage returns nutrient back to soil as litter (Dubeux et al., 2007). The quantity of nutrients returned might be affected by ICLS. For example, Carpinelli et al. (2020) quantified dung deposition and nutrient release from cattle grazing two different ICLS, one with trees and another without. The authors reported greater dung patch number in the system without trees, providing it had greater stocking rate (Carpinelli et al., 2020). In addition, systems without trees had greater total N, P, K, and S release compared to systems with trees.

Grazing management plays a key role in ICLS. Moderate and light grazing had similar increases in total organic C, particulate organic C, total N, and particulate organic N compared with no grazing (Assmann, J.M. et al., 2014). However, heavy grazing resulted in soil N loss due to soil organic matter degradation (Assmann et al., 2014). Furthermore, dung composition may change according to the plant vegetative stage. Phosphorus and K concentrations were 16 and 7% greater, respectively, when sheep were grazing Italian ryegrass pasture (*Lolium multiflorum* Lam.) in the vegetative stage compared to post-flowering (Arnuti et al., 2020).

Inter-crop livestock system that includes perennial forages into the rotation can also increase nutrient cycling. Perennial forages have root systems that penetrate deep into the soil and scavenge nutrient from deeper soil layers. The root system of perennial grasses, such as bahiagrass (*Paspalum notatum* Flüggé), can also contribute greatly for the soil C pool. Santos et al. (2019) reported a C stock in roots and rhizomes of bahiagrass ranging from 4.5 to 8.6 Mg ha^{-1}. Moreover, ICLS may reduce nutrient leaching to the ground water. In a cotton cropping system, nitrate losses to ground water were reduced when grazed cover crops were added during the cool season, compared to systems where plots were not grazed during the cool season (Figure 1; Santos et al., 2022a).

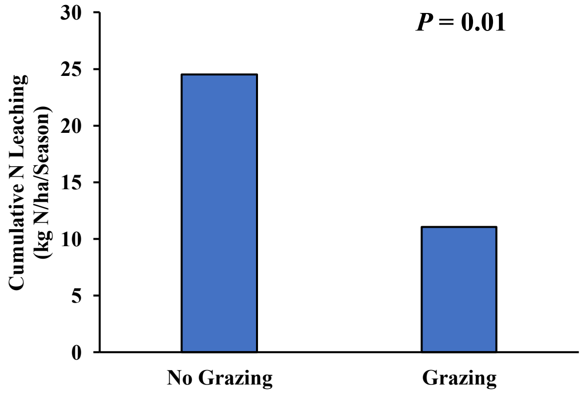

Figure 1. Grazing may reduce N leaching in crop-livestock systems. Adapted from Santos et al. (2022).

Plant litter decomposition is another important pathway of nutrient cycling in agroecosystems. Decomposition of dual-purpose wheat residue was enhanced in places where grazing took place before, however, these changes were relatively small (Assmann et al., 2014). Santos (2020) indicated that heavy grazing improved quality of aboveground cover crop litter, resulting in faster decomposition rate compared to non-grazed plots. However, heavy grazing resulted in greater weed encroachment and lesser soil cover compared no non-grazed plots (Santos et al., 2022b). Systems containing trees may also benefit from the decomposition of litterfall. Apolinário et al. (2016) reported that N amounts cycled via leaf decay of two leguminous trees in a perennial grass system ranged from 87 to 109 kg N ha^{-1}.

Crop Responses

Specialized agriculture production with high levels of inputs has been established as the most common method of food production in the past century (Duru et al., 2014). Exclusive single cropping systems have led to cheaper and easier access to once expensive foods. However, agricultural specialization has brought other problems such as larger environmental impact, low sustainability, and loss of biodiversity (Rai et al., 2020).

Grain-grazing associations in agroecosystems provide multiple benefits associated with increased productivity and food safety without compromising sustainability. Long-standing uses of integrated production systems have higher outputs in comparison to those that rely on conventional management practices (Peterson et al., 2020). Specialized systems are overtaken by integrated ones specially because these associations between multiple components result in additional ecosystem services such as enhanced soil structure, soil fertility, carbon sequestration, nutrient cycling, and rangeland restoration (Sanderson et al., 2013).

In the long term, crop yields tend to be greater in diverse cropping systems when compared to those that have focused on specialization. Integration processes contribute to organic matter accumulation enhancing soil physics and health characteristics such as water holding capacity, soil tilth and other soil properties resulting in greater grain yield potentials and profit (Ruselle et al., 2007; Katsvairo et al., 2006).

As an example of sustainable agriculture, ICLS are more persistent and resistant to climate changes (Sekaran et al., 2021). Specialized farm practices can decrease up to 75% the total production system revenue, whereas the integrated system falls only a 10% under the same climate change scenario (Seo, 2010). Production system diversification can increase resource use efficiency by providing benefits to all individual constituents of integrated crop-livestock systems. Food supply to livestock, soil coverage, reduced erosion, better water holding capacity and greater soil organic carbon content are some of the examples on how each unit plays a major role on interconnecting their roles leading to sustainable agriculture intensification (Sekaran et al., 2021; Franzluebbers, 2007).

Implications

Integrated crop-livestock systems provide an array of benefits, including increased crop productivity and nutrient cycling, and improved farm resilience. In a changing world, recombining crops and livestock is not only a means to increase profit, but to create a more sustainable system capable of overcoming the challenges imposed by a warming climate and a growing population.

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