Carbon, Nitrogen and Phosphorus Cycling in Cropland and Grassland Ecosystems

Katja Klumpp

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Editorial

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Katja Klumpp

Unité de Recherche sur l'Ecosystème Prairial, INRAE, VetAgro Sup, University Clermont Auvergne, 63000 Clermont-Ferrand, France; katja.klumpp@inrae.fr; Tel.: +33-443-76-16-10

Croplands and grasslands have a multifunctional role in biomass production for livestock and human needs. However, some of those systems are either constrained by the availability of resources such as nutrients and water, or being characterized by nutrient losses, or inefficiencies in internal nutrient cycling and poor synchronization of nutrient availability with plant demand and nutrient supply. With the increase in global demand for agricultural and food products, the development of new sustainable agricultural strategies reducing negative environmental impacts has become most important. However, given the geographic spread of grasslands and croplands, accompanied by differences in crops, cropping systems and agricultural practices imply the definition of site (region)-specific approaches.

These site- and region-specific approaches may comprise the use of nitrification inhibitors, either biochemical [1] or biological (i.e., Brachiaria grass, *Brachiaria* spp.) [2], to reduce N losses (lixiviation and emissions) and improve N-use efficiency in a wide variety of soils that vary from N-fertilized agriculture to pasture soils. Then again, some areas are limited by N, while others are limited by phosphorus (P). For instance, to supplement P, intercropping with legumes delivering an enzyme activity (i.e., acid and alkaline phosphatase) and thus more available nutrients, might be a sustainable way [3,4]. Besides, to prevent nutrient leaching and erosion related to intense crop removal, some cropping systems may require the application of combined techniques including biochemical and organic fertilization, and intercropping [5], whereas other production systems, in particular semi-arid regions, may need novel land-use strategy schemes to provide sustainable agricultural systems [6]. The transition towards those more sustainable systems often needs further analyses, especially when involving arable systems in relation to an evolution from and to more perennial systems (i.e., wood vs. food production) [7,8].

Among the strategies towards sustainable land use, integrated crop–livestock systems (ICLS) have gained additional interest concerning improvements of soil fertility and nutrient cycling [9,10]. Besides recoupling of nutrient cycles, an additional inclusion of agroforestry in those systems may provide further benefits such as shelter and shade for animals [4]. At the same time, the presence of grazing domestic animals does involve other features of nutrient cycling such as spatial heterogeneity in above- and belowground nutrient pools (C–N–P), related to the uneven defoliation pattern and distribution of dung [4,6]. In these often grass-based livestock systems, observations of plant community structures and plant functional types (PFTs) have been proved to be a useful tool to predict processes related to biomass production and C–N–P cycles [7,8].

The special issue provides an overview of C–N–P cycling for an array cropland and grassland ecosystems in relation management practices worldwide. It includes 11 original research articles that provide insights of possible solutions and proxies when hoping to improve C–N–P cycling through sustainable management. These papers are broadly focused on farming system design, crop rotation, N management, residue management, and grassland management.

N cycle and Fertilization. Fertilizer supply in excess of plant demand increases greenhouse gas emission (i.e., nitrous oxide (N_2O) and nitrogen leaching from the root

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zone. Nitrification inhibitors have been widely used to reduce N loss and to improve N-use efficiency in a wide variety of soil that varies from fertilized arable to pasture soils. Although previously assessed [11,12], the interaction between the inhibitory effect under different soil properties and soil nitrification potential remain poorly understood. The paper by Mukhtar and Lin [13] evaluates the effect of soil nitrification potential (NP) on the efficiency of nitrification inhibitors (NI, dicyandiamide (DCD) and 3,4-dimethypyrazole phosphate (DMPP) application rates for different temperature ranges among land-use type. Among land-use types, authors tested eight cropped and non cropped soils of different climate regions of Taiwan. Temperature did not appear to have effect on inhibition effect of NI products, suggesting a wider range of application possibilities. The inhibitory effect for both chemical products, however, decreased with soil nitrification potential, implying lower application rates for soils with low NP rates.

In addition, biological nitrification inhibition (BNI) has been attracting attention as a technology for effective N utilization in cropping systems and pasture [14]. Brachiaria cultivars have been reported to suppress nitrifier populations by releasing nitrification inhibitors from roots through exudation [15]. The article by Nakamura et al. [16] evaluated the biological nitrification inhibition of root exudates for different Brachiaria cultivars with respect to root biomass production and root turnover of cultivars. Here, authors monitored root growth in relation to changes in ammonia-oxidizing bacteria (AOB) and ammonia-oxidizing archaea (AOA) numbers, subsequent nitrification rate, and available nitrogen (N) content under seven germplasm lines of Brachiaria. Biological inhibitory effect on nitrification was mostly evident in AOA, and not in AOB for three Brachiaria cultivations.

Cropping Techniques to Improve Nutrient Cycles. Biomass mass production can be also limited by phosphorus and nitrogen, in particular under acidic and nutrient-poor soil conditions. Various mechanisms exist to mitigate P deficiency and/or stress [17]. Several studies have reported the beneficial effect of cereal–legume intercropping for P and N acquisition [18]. Among legume crops, *Vigna unguiculata* L. Walp (Cowpea) was suggested to combine both provision of proteins for alimentations and improvement of P status via its significant acid and alkaline phosphatase activity when used as intercrop [19]. In order to analyze the compromise between intercropping and inorganic fertilization, Mndzebele et al. [20] evaluated the benefits of acid and alkaline phosphatase activity of cowpea intercropping in *Amaranthus cruentus* under varying levels of NPK fertilization. Treatments included non-N-fertilized control, and N applied with 25%, 50%, and 100% of the recommended NPK levels. The cowpea and amaranth plants grown without fertilizer or 25% NPK had the highest rhizospheric phosphatase activity, while 100% NPK application exhibited the least. Plant tissue phosphorus concentration in plant biomass increased proportionately to the increased fertilizer application of up to 50% of the recommended NPK level. The higher phosphatase activity from the low fertilizer application treatments indicated the beneficial effect of cowpea intercropping and low fertilization.

In addition, intercropping with chickpea (*Cicer arietinum* L.) might ease the P or N deficiency in alkaline soil. The paper by Latati et al. [2] assessed the performance chickpea intercrop with durum wheat on soil properties and biomass production improvements for alkaline soils (pH varying from 7.5 to 8.5) in northern Algeria. Both the aboveground biomass and grain yield and, consequently, the amount of N taken up by intercropped durum wheat increased significantly (44%, 48%, and 30%, respectively) compared with sole cropping. Moreover, intercropped chickpea considerably increased N (49%) and P (75%) availability in durum wheat rhizosphere, grain yield, and resource N- and P-use efficiency, underlining the beneficial effect of chickpea intercropping.

Besides nutrient improvements, intercropping may be used as agricultural practice to improve the soil organic matter in nutrient imbalanced degraded long-term monocultures. Depending on main crop, many kinds of intercrops can be applied, improving one or several aspects of soil properties. Accordingly, combined methods might sometimes be useful to restore soil fertility. To restore soil properties and N–P–K cycling of a degraded coffee tree plantation, the article by Pham et al. [1] analyses a series of "rejuvenation strategies" for coffee. Among combined treatments seeking to increase survival rate of seedlings on replanted land, authors assessed biochemical (NPK fertilizer) and organic treatments (i.e., liming) combined in short-term crop intercropping (Mexican marigold, *Tagetes erecta*) and microbial organic fertilizer (manure), and green manure applications. Among treatments, the burying of green manure and intercropping combined with microbial fertilizer performed the best on the fertilities of replanted coffee soil. In addition, tillage practices and liming had an effect, underlining the need to carefully study combined methods when liking to restore soil fertility.

Land-Use Strategies. In recent decades, research on land-use strategies related to C sequestration and greenhouse gases emissions has gained importance [21,22], with the emphasis on combining food and fiber production. In particular, the growth of multi-stemmed woody material, such short-rotation coppice (SRC, with poplar, *Populus L.* spp.), has become an issue in Northern and Central Italy due to increasing limitations in terms of rapid decline of biomass production over years, a high water demand, and high destruction costs. A shift from an SRC stand to other land uses into a silvo-arable alley-cropping system (ACS) has gain interest in Central Europe [23]. The article of Pecchioni et al. [5] assessed the C storage potential of alley-cropping systems (poplar and sorghum, *Sorghum bicolor* L. Moench) compared to the classical short-rotation coppice cultivation system for Central Italy. In the first year of the transition, converting the SRC into an ACS, a greater C storage was observed in pure tree belowground biomass compared to the silvoarable. The incorporation of residues and tillage disturbance in the alley has led to high respiratory losses during transition phases. However, additional years of measurement are necessary to determine turnover and extent of C losses.

In some areas, traditional land-use changes do comprise management practices, such as biomass burning, residue removal, conventional tillage, clean cultivation, monoculture, and intensive grazing; some of them leading to soil degradation [24]. This process might be more intense in areas of poor temporal and spatial distribution of rainfall, such as in seasonally dry tropical forests (i.e., found in five continents, South America, northern Paraguay, part of Argentina, southwest of Bolivia, and Northeast Brazil). Questions on sustainable land-use strategies to supply both fiber and protein production and soil health and fertility (i.e., soil carbon and nitrogen) has gained interest in recent years. The article by Andrade et al. [3] evaluates effects of four main land uses on soil C/N stocks in a semi-arid region of Brazil. Among analyzed land uses, authors visited dense and open caatinga (i.e., area protected from cattle grazing and under forest regeneration), long-term pastures, and arable land cultivated with rain-fed maize (*Zea mays*. L.) or bean (*Phaseolus vulgaris)*. The study underlines that, though most of the land uses were established for more than 10 years, land-use effects on total organic carbon and nitrogen content were mostly observed in the top soil layer (0–10 cm) rather than the deeper soil layers. Those results foster the possibilities to produce biomass and proteins in dry tropical forests on Neosols with very low total organic carbon stock when applying different land uses. Nonetheless, additional studies are recommended to quantify the carrying capacity of livestock when maintaining a thinned forest.

Integrated Livestock-Cropping Systems. Sustainable intensification though the inclusion on livestock in conventional arable systems have shown several medium- and long-term advantages [25,26]. Numerous studies underline the improvements of soil fertility and nutrient cycling related to integrated crop–livestock systems (ICLS). Further integration of trees may also deliver diversification of the producer's income sources, consideration for animal welfare, and rational water use. The paper by Carpinelli et al. [4] evaluated impacts of the presence of trees exerted on excreta distribution, as well as nutrient cycling for an ICLS under humid subtropical climate in Southern Brazil. Authors' objectives were to map the distribution of cattle dung in two ICLS, i.e., with and without trees, and to quantify soil nutrient cycling related to dung dry matter decomposition. The nutrient from cattle dung was less in systems with trees compared to systems without trees, partly related to lower animal stocking densities in systems with trees. Tree systems seemed, however, to foster a more homogeneous spatial distribution of the dung compared to ICLS without trees, underlining the need to further progress in sustainable fertilization management.

Grassland Systems. Descriptions and quantification of the spatial heterogeneity in plant and soil properties and their role in biogeochemical cycling, nutrient losses related to grazing livestock, and management are extremely limited [27]. Hence, to define sustainable management recommendations, an improved understanding of the impacts of different management practices on the expression of spatial heterogeneity such as the occurrence and degree variability and spatial pattern of plant and soil, is required. The article of Bloor et al. [6] have carried out a spatially explicit sampling campaign and geostatistical analyses to quantify the spatial heterogeneity of the biomass and N in plants and soil for three grassland managements (mowing, cattle grazing, and sheep grazing) within a long-term grassland experiment in France. Compared to the sheep-grazed field, the cattle-grazed field had a higher degree of spatial structure and a more coarse-grained pattern of spatial heterogeneity in plant properties. Both grazing managements showed spatial asynchrony in above- and belowground responses to grazing. These findings demonstrate the importance of herbivore species identity for the spatial uncoupling of nutrient cycles at the field scale.

For grassland in mountain areas, soil functioning is particularly affected by the combination of livestock grazing and the inter- and intra-annual variability in precipitation and temperature [28]. Among soil processes there are processes of N-turnover such as nitrification and denitrification processes both being regulated by temperature and soil moisture, as well as C availability [29]. Subsequently, it is essential to assess the potential and rates of de/nitrification as having severe effects on soil activity and fertility. The article of Debouk et al. [7] investigated the importance of environmental factors (climatic, management, and soil) and plant functional diversity (PFT composition and interactions) on soil activity and fertility along a climatic gradient in the Northern Iberian Peninsula. Analyses comprise six extensively managed grasslands, ranging from semi-arid up to alpine grasslands with a low-intensity seasonal grazing, varying from warm continental in the low-altitude sites, to cold temperate conditions in the high-altitude sites. Among tested factors, management variables explained most of the variability (96.5%) in soil activity and fertility compared to plant function types (PFT; grasses, legumes, and non-legume forbs), which accounted for 27% of the total variability. The soil activity and fertility is, accordingly, a mixture of environmental variables (soil–climate–agricultural practices) and related PFT diversity.

The PFTs and related strategies (e.g., growth, nutrient uptake) can be associated with a set of plant functional traits such as leaf traits [27], which depend themselves on the relative abundance of the species in the assemblage (e.g., specific leaf area (SLA), leaf dry matter content (LDMC). However, relationships between community-level leaf traits and soil processes, such as soil C inputs and subsequent soil C sequestration, remain to be further explored. The article of Kohler et al. [8] examined a set of seven temperate grasslands in Normandy (France), differing in age (i.e., from a 1-year temporary grassland to old permanent grasslands >30 years) and management practices for the relation between traits, annual net primary productivity, C allocation to belowground, and soil organic C. A higher biomass production occurred under low soil organic C stocks. This negative relation between production and soil organic C could be linked to plant community functioning, and particularly leaf dry matter content, but also grassland age. Hence, analyses suggest a direct effect of management and grassland age on plant community, which in turn affects plant tissue quality and subsequent soil organic C.

In conclusion, several strategies facilitate the (re-) coupling of C–N–P cycles. This special issue contains articles for an array of cropland and grassland agroecosystems and management practices worldwide. Articles embrace various objectives and methodologies, on how new sustainable agricultural strategies can contribute to reduce negative environmental impacts. Similarly, this special issue demonstrates ways to address the complexity of nutrient cycling and its current and future challenges, allowing guiding field and on-farm adoption of (best) management practices.

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