Improved Plant Diversity as a Strategy to Increase Available Soil Phosphorus

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Crop rotations associated with soil conservation management have been suggested as a suitable strategy to enhance soil health and nutrient availability. Conversely, monoculture systems may not be able to reach sustainable soil management by recycling nutrients. Increasing both the quantity and quality of crop residues in diversified cropping systems can provide multiple ecosystem services, such as recycling nutrients and increasing soil organic matter. The impacts vary widely according to the crop species, residue composition, soil textural class, climate, soil management, and their interactions. However, little attention has been directed toward understanding relationships between functional plant diversity, nutrient cycling, and soil P availability (Faucon et al., 2015). In this article we highlight some strategies to improve the P availability in cropping systems.

Release of Phosphorus by Crop Residue Decomposition

Indirect impact on P availability may be attributed to cropping systems by the biochemical crop residue compositions, including the C:N and C:P ratios, as well as the soil biodiversity. The P concentration of the crop residue is a main factor determining whether P will be mineralized in the short-term as a result of residue decomposition. These characteristics can promote microbial diversity, which may result in a positive effect on P availability and crop growth.

In the crop tissue, the soluble inorganic phosphorus (P_{si}) fraction represents the highest P content, primarily stored in the vacuole, which is released in early stages of crop residue mineralization. However, more recalcitrant P fractions tend to have their proportions increased in residues as they are present in organic compounds that depend on biochemical composition of the crop residue and mineralization for P release. In general, crop species with a lower C:N ratio as well as lower lignin content stimulate the release of P, whereas, the release of P occurs over time in species with a higher C:N ratio and higher lignin content. Cereal crop residues tend to have lower P concentrations and higher C:P and C:N ratios, which results in a lower potential for mineralization during decomposition compared to crops with lower ratios. Therefore, under conditions of low inorganic P (P_i), soil P_i may be assimilated by microbial biomass, decreasing crop P availability. In this sense, the cropping system has the potential to either limit or increase soil P availability.

Cropping systems, as regulators of the plant-available nutrient supply, must be addressed to boost residue P recycling. The inclusion of palisadegrass (*Urochloa brizantha)* in a cropping rotation provided greater available nutrient contents in the soil, increasing soybean, white oat, and maize yield as main crops (Crusciol et al., 2015). A crop rotation experiment assessing the impact of ruzigrass (*Urochloa ruziziensis*) on soybean yield, indicated that the ruzigrass did not affect soybean yield compared to a fallow field (Merlin et al., 2013). However, cropping ruzigrass for consecutive years at the same experimental site did result in a decrease in soybean yield compared with the legume as monoculture (Almeida et al., 2018). According to the authors, ruzigrass may keep P immobilized in crop residue, affecting the P nutrition of soybean. Therefore, P release through crop residue mineralization may be related to a synchrony between soil P availability, the mineralization process, and the demand by the main crop.

Some plants have enhanced capacity to take up P from soil under low concentration by increasing their phosphatase activity and then accumulating P in their tissues (Faucon et al., 2015). This may reduce the chemical fixation, decreasing the time of P exposure to soil particles. This approach could be important for highly weathered soils. Other strategies to increase P uptake may address arbuscular mycorrhizal symbioses. The mycorrhizae provide an effective pathway by which P is scavenged from larger volumes of soil and rapidly delivered to cortical cells within the root, bypassing direct uptake (Smith et al., 2011). However, the diversity of responses to inoculation with mycorrhizal fungi

SUMMARY

Some crop species could be used inside a cropping system as part of a strategy to increase soil P availability due to their capacity to recycle P and shift the equilibrium between soil P fractions to benefit the main crop. The release of P by crop residue decomposition, and mobilization and uptake of otherwise recalcitrant P are important mechanisms capable of increasing P availability and crop yields.

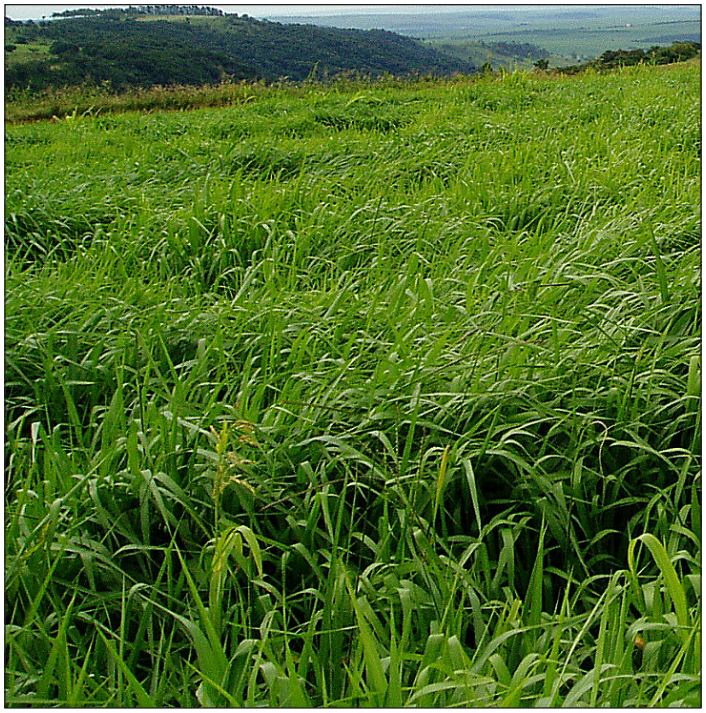
KEYWORDS:

P release from crop residue; main crop yield; P solubilization

ABBREVIATIONS AND NOTES:

P = phosphorus; P_o = organic phosphorus; P_i = inorganic phosphorus; P_{si} = soluble inorganic phosphorus; N = nitrogen; SOM = soil organic matter

https://doi.org/10.24047/BC103143



Ruzigrass (*Urochloa ruziziensis*) left, and **Palisadegrass** (*Urochloa brizantha*) right, have been studied in Brazil to determine their impact on P availability to main crops in the rotation system.

is widely recognized due to the ecosystem conditions and cropping management strategies.

Mobilizing Recalcitrant Soil Phosphorus

Although there are not many cases, a few cover crop species are reported to efficiently take up less-labile P forms. Introduction of these species into cropping systems could improve P availability to main crops (i.e., those with less ability to mobilize recalcitrant P forms). Phosphorus-mobilizing crop species improve P nutrition due to rhizosphere related traits of multicropping systems by releasing acid phosphatases or phytases. These conditions hydrolyze P_o to release P_i, protons and/or carboxylates in soils, decreasing P sorption on Al and Fe oxide and hydroxides. Malate and citrate are carboxylates that mobilize P bound to Ca in calcareous soil and P bound to oxides and hydroxides of Al and Fe in acid soils (Hinsinger, 2001). For example, fababean releases protons, malate, and citrate into the rhizosphere, mobilizing insoluble soil P. Chickpea accesses P_o by exudation of acid phosphatases, which hydrolyze P_o into P_i, facilitating P acquisition by wheat or maize grown in an intercropped system (Lambers et al., 2011). According to the literature, some intercropping systems have been reported to encourage interspecific facilitation of P acquisition by P-mobilizing species: wheat intercropping with *Lupinus albus*/chickpea (both

Chickpea (left) and **Fababean** (right) have been shown to mobilize or facilitate access to less-labile forms of soil P.

Table 1. Examples of crop rotations in which yield improvements were attributed in part to improved P nutrition.

Main crop	Cropping systems	Yield, t/ha	Authors
Maize	Monocropping	12.8	[1]Li et al. (2007)
	Fababean/maize rotation	18.9	
	Continuously intercropped with fababean	17.3	
Maize	Monocropping	9.1	[2]Wang et al. (2014)
	Intercropped with fababean	11.0	
	Intercropped with soybean	12.6	
	Intercropped with chickpea	12.4	
Potato*	Monocropping	35.5	[3]Gitari et al. (2018)
	Intercropped with pea	37.7	
	Intercropped with common bean	40.3	
	Intercropped with *Lablab purpureus*	43.1	
Wheat	Rice/wheat rotation	2.4	[4]Bai et al. (2013)
	Maize/wheat rotation	2.7	
	Soybean and maize/wheat rotation	3.1	
Soybean	After 2 years of maize/fallow	3.4	[5]Crusciol et al. (2015)
	After 2 years of maize intercropped with *U. brizantha*	3.7	
White oat	After 2 years of maize/fallow/soybean	1.5	
	After 2 years of maize intercropped with *U. brizantha*/soybean	1.9	
Maize	After 2 years of maize/fallow/soybean/white oat	8.7	
	After 2 years of maize intercropped with *U. brizantha*/soybean/white oat	9.9	
Type of influence in P availability			

[1] Facilitated P uptake by maize because fababean acidified its rhizosphere, and exuded malate and citrate into its rhizosphere mobilizing insoluble P_i in soil.
[2] Intercropping enhances soil acid phosphatase activity compared to monocropping.
[3] Suggest the *Lablab purpureus* produces exudates such as phosphatases and carboxylates, increasing P availability to the companion crop
[4] Suggest the release of proton and carboxylates exudation by maize roots and mobilizing soil Pi in calcareous soil.
[5] Suggest the action of low molecular-weight organic acids exuded by the roots.
*Potato equivalent yield.

P-mobilizing species); sorghum intercropping with *Cajanus cajan* (P-mobilizing species); maize intercropping with peanut/fababean (both P-mobilizing species) (Li et al., 2007; 2014).

Intercropping P-mobilizing and non-P-mobilizing crop species creates a temporal and spatial niche enhancing the capability to exploit soil P by colonizing the soil profile and increasing the total soil volume occupied by these species compared to a monoculture (Li et al., 2014).

Research studying the yield improvements arising from interspecies interactions within cropping systems and improvements in P nutrition has been limited, but some examples are listed in **Table 1**. There is some agreement based on the studies reviewed, that increasing soil P availability in cropping systems requires: soil management and P fertilization; incorporating species with the ability to mobilize insoluble soil P into monoculture cropping systems; and a better understanding of the release of P from crop residue decomposition.

Considerations

Studying the recycling of P in cropping systems with a focus on P availability is a challenge due to soil-plant interactions. The strategies summarized in this article address soil management to increase available P, with a focus on recycling P and shifting the equilibrium between soil P fractions towards plant-available fractions in cropping systems. Great efforts are necessary in this applied research field to maintain sustainable strategies on cropping systems management concerning crop P recycling. **BC**

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