Increasing Plant Access to Legacy Phosphorus, with a Focus in the Tropics

By Luís I. Prochnow, Heidi Peterson, and Tom Bruulsema

Phosphorus (P) is one of the most studied nutrients for plant nutrition worldwide and there are many concerns regarding the availability of its finite reserves and resources for future generations. For tropical soils, predominantly with an oxidic or 1:1 mineralogy, P gains even more attention due to its high potential to be fixed into forms less available to plants. Currently, this nutrient is normally applied to soils in higher amounts than removed, which leads to a stock of P in less available forms in the soil (i.e., residual or legacy P). Recently, researchers have been calculating this legacy P and discussing possibilities to increase its recovery and decrease P input dependency in a near future. The cumulative surplus of P applied to cropland between 1900 to 2016, over that removed by crop harvest during the same time interval was recently calculated to be about 30 million (M t) for Brazil (Withers et al., 2018). This is compared to about 40 and 65 M t for the U.S. and Western Europe, respectively, calculated from data presented in Mogollón et al. (2018). Considering that all three of these regions feature highly productive cropping systems, it is reasonable that large legacies of P may have accumulated in other regions with similar levels of productivity.

There are industrial and agronomic practices that may increase efficiency of P use from phosphate rock (PR) mining to field operations. Recovering part of the legacy P in soils seems to be one potentially profitable option. Although much of the legacy P may have been transformed over time into forms of low availability, the agronomic practices discussed in this paper have the potential to help plants to access some of those forms. The focus is specially on acid soils of the tropics, but some of the techniques can be applied to a variety of soils around the globe.

Management of Soil Acidity with Lime and Gypsum Application

Liming improves both positional and chemical availability of plant nutrients. It improves soil aggregation and tilth, resulting in greater root proliferation. When soil pH is optimum, plants develop more finely divided and extensive root systems, and are better able to utilize nutrients present in both surface and subsoils. Changes in soil pH affect the availability of the various plant nutrients differently, as illustrated in **Figure 1**. The availability of most nutrients, including P, is greatest in the soil pH range of 5.8 to 7.0. Besides increasing the availability of nutrients, one of the most important benefits of liming is the reduction in the activity of toxic elements like Al, and sometimes Mn and Fe.

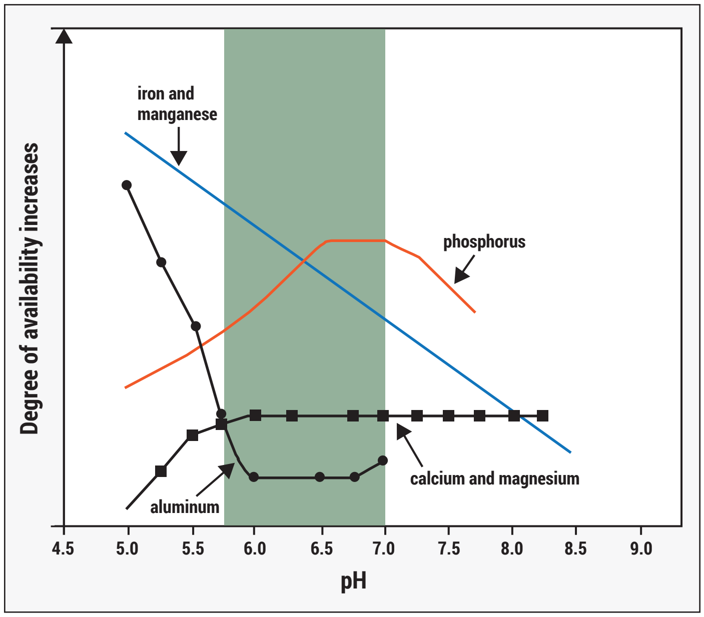

Figure 1. Typical effect of change in soil pH on the availability of some of the plant nutrients and also aluminum (Adapted from Malavolta, 2006).

Chemically gypsum is a neutral salt with no direct effect on soil pH. However, many researchers have shown that it can ameliorate subsoil acidity with positive influences on plant root development. Because gypsum has higher water solubility than lime, it can dissolve and leach through the soil profile adding significant amounts of Ca and sulfate (SO_4^{2-}) at soil depths where lime would not reach. The increase in SO_4^{2-} concentration in deeper soil layers favors the formation of the ion pair aluminum sulfate ($AlSO_4^{-}$), which diminishes the activity of Al^{3+}. As a result, the toxicity of Al^{3+} is decreased, and at the same time the availability of Ca is increased, thus favoring the elongation of plant roots in

SUMMARY

Tropical soils have a high tendency to convert applied P into less available forms. This article discusses readily adoptable agronomic practices that have good potential to help plants to access this pool of "legacy P."

KEYWORDS:

legacy phosphorus; tropical soils; no-till; gypsum; intercropping

ABBREVIATIONS AND NOTES:

P = phosphorus; Ca = calcium; Al = aluminum; Fe = iron; Mn = manganese

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Beans under no-till done right. Note the favorable amounts of residues from previous crops in the soil surface.

Table 1. Effect of phosphogypsum (PG) application on the development of root systems at different soil depths in different crops from different parts of the world.

	Corn root density (South Africa)[1]		Corn % relative distribution of roots (Brazil)[2]		Apple root density (Brazil)[3]		Alfalfa root length (USA)[4]	
Soil depth	C[(1)]	PG[(2)]	C	PG	C	PG	C	PG
cm	--- m/dm^3 ---		---- % ----		--- cm/g ---		--- m/m^3 ---	
0-15	3.10	2.95	53	34	50	119	115	439
15-30	2.85	1.60	17	25	60	104	30	94
30-45	1.80	2.00	10	12	18	89	19	96
45-60	0.45	3.95	8	19	18	89	10	112
60-75	0.08	2.05	2	10	18	89	6	28

C = Control; Sources: [1] Farina and Channon, 1988; [2] Sousa and Ritchey, 1986; [3] Pavan and Bingham, 1986; [4] Sumner and Carter, 1988.

this acidic subsoil. **Table 1** shows results from studies in different parts of the world on the development of plant root systems with and without application of phosphogypsum (PG), which is a by-product in the production of phosphoric acid. Clearly, PG application helped develop better root systems at soil depths beyond 30 cm. One major concern with the use of PG is the amounts of radioactive elements it may contain. A careful characterization of PG is therefore necessary before using this material as a soil input to ameliorate subsoil acidity.

Both lime and gypsum create better soil conditions that favor root elongation, plant development, and consequently higher yields. More roots mean more soil explored and more favorable conditions to absorb nutrients and water. Thus, these techniques can increase access to legacy P.

No-till Done Right

It is well-known that no-till done right, in terms of crop rotation and more residues at the soil surface, leads to less erosion, higher amounts of soil organic matter (SOM), and better soil physical conditions. Results have been so successful that land area under no-till has been increasing dramatically over conventional tillage systems in many tropical regions of the world. One of the effects of no-till in terms of nutrient availability is that higher contents of SOM, by protecting sites of P adsorption and/or by replacing P in such sites, leads to higher P availability. Also, better soil physical conditions lead to more soil explored by plant roots and higher chance for P uptake. Among others, these effects indicate that no-till done right can lead to more of the legacy P used by plants.

Crop Rotation and Intercropping Grain Crops with Grasses

Recently, several studies have shown the advantages of integrating grain with certain type of grasses for increasing soil health and yields with time. Many grasses have robust and deep root systems, show high tolerance to water stress, and consequently can develop well in conditions where the great majority of grain crops, and some conventional cover crops, do not.

Many authors have also noticed that some of these grasses improve cycling and availability of nutrients in the soil system, particularly P. As an example, **Figure 2** shows the increase in the plant-available P between 5 to 40 cm when corn was intercropped with palisade grass (*Urochloa brizantha*), as opposed to monocropped with corn. There are indications that the increase is due to more P extracted from slowly soluble forms by the palisade grass. Field studies in Brazil indicated that P recovery over fifteen

Intercropping of corn and the grass *Brachiaria brizantha*.

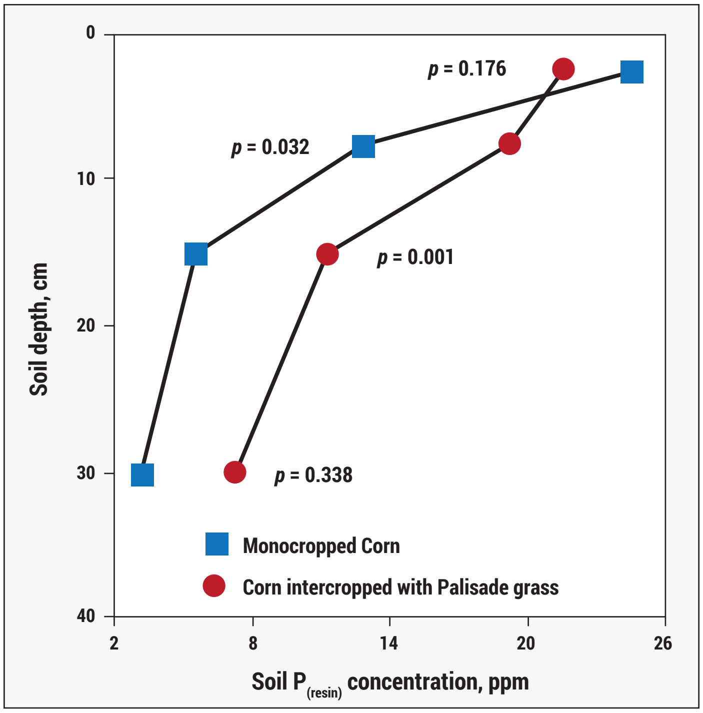

Figure 2. Farming systems including grasses may increase the plant-available soil P through the soil profile in well-managed no-till systems (Crusciol et al. 2015).

or more years under cropping systems including grasses, like *Urochloa brizantha* and *Panicum maximum*, can be in the order of 85% over the years, while just around 40% was recovered when only soybean and/or corn was cultivated. These results suggest that more of the legacy P can be accessed by plants when adequate grasses are intercropped or used in sequence with other species.

Due to differences in the ecosystems and plant characteristics it is important to study the best type of crop rotation for each region. There is no general rule for recommending a crop sequence amongst the diverse agricultural areas of the globe, but keeping green cover over soil for a significant proportion of the year will generally contribute more carbon to the soil, which with time will be agronomically and environmentally beneficial.

Regarding crop rotation and tillage practices that increase SOM, these practices will only be successful in soils where P is not limiting plant growth. Phosphorus inputs will often be necessary to obtain this condition. That means these practices will not be effective in soils with low amounts of plant-available P. Soil fertility needs to be built with time so that other practices can work well.

Phosphorus-efficient Crops and Cultivars

Different crops have different requirements concerning P availability in the soil. As an example, it is estimated that soybean needs a P concentration in soil solution that is 20 times higher than what peanut crops need to reach 95% of their maximum yields. Also, some species have developed strategies to improve their capacity to absorb P from the soil, rending less available forms of P into forms accessible to them under P-limiting conditions. These strategies include improved uptake efficiency (ability to take up more P under P-limiting conditions) and/or improved use efficiency (ability to produce higher dry matter yield per unit of P taken up). Some of the uptake efficiency include modification of root architecture, development of more ample root systems, longer root hair and thinner roots, higher root-shoot ratio, exudation of low molecular weight organic acids, and stronger association with mycorrhiza. Breeding programs can use such traits to improve the use of soil P. From the above it is clear that plant species or genotypes of the same species with higher P uptake efficiency can lead to higher use of the legacy P in the soils.

4R Nutrient Stewardship

Applying the right source, at the right rate, at the right time, and in the right place is key to achieving efficient use of nutrients and higher yields. These practices, in conjunction with other seeding, plant protection, and irrigation management practices can improve plant development favoring plant health, root elongation, and consequently, more absorption of water and nutrients. As an example, it is clear that positioning of P in furrow, and not just broadcasting on the soil surface, can lead to root elongation and more volume of soil explored, which with time may translate into more of the legacy P used by different crops.

Conclusion

All the practices above should be seriously considered in strategic plans to recover a portion of the legacy P from tropical soils, which will optimize P resources, benefiting farmers and food security in the medium to long run. It is expected that scientific development will result in the availability of new management technology, crop varieties, and plant protection products that can lead to better use of the soil's legacy P. **BC**

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