# Phosphogypsum Use to Reduce Subsoil Acidity: The Brazilian Experience

By Luís Prochnow, Eduardo Caires, and Camila Rodrigues

**Phosphogypsum can help** to improve subsoil conditions in certain circumstances, which favors plant root development.
**Better root growth** in acidic soils translates into increased water and nutrient uptake by crops leading to higher yields, profitability, and sustainability

It is estimated that at least 50% of agricultural soils in the world are acidic (i.e., low soil pH), a condition that severely affects the development and yield of most commercial crops. The most common effects of soil acidity are: toxicity to $Al^{3+}$, low availability of plant nutrients, poor soil physical and microbiological conditions (including symbiotic N fixation in legumes), and low effectiveness of certain herbicides.

The improvement of soil and subsoil acidity is a key management practice for high yields, profitability, and sustainability. Research shows positive response to acidity-reducing inputs for a wide range of crops, with yield gains as high as 500%. A major component of soil acidity management is the application of lime but other practices, mainly phosphogypsum (PG) use and cultivar selection, are beneficial. Examples provided below highlight the Brazilian experience, but this information is relevant to many regions affected by subsoil acidity.

## Phosphogypsum Properties

Phosphogypsum ($CaSO_4 \cdot 2H_2O$) is a by-product of phosphoric acid production and PG's most common agricultural uses are as a direct source of Ca or S to plants, an additive during manure composting, for improvement of saline-sodic soils, and for reduction of subsoil acidity. Generally, the main constraints for any particular PG source are its chemical and physical properties, as well as any prohibitive cost of transportation. Pre-treating PG to improve its quality (i.e., creating a product with lower moisture and a more uniform particle-size) can improve PG product acceptability. Legislative limits to radionuclide concentrations in soil amendments can limit or even prohibit the use of PG for many regions of the world, but this issue is under continuous review. Sedimentary phosphate rock sources have higher radioelement concentrations compared to phosphate rock from igneous sources.

Chemically, PG is a neutral salt with much higher solubility than lime and with no direct effect on soil pH. While aglime (Ca and/or $MgCO_3$) can increase soil pH, due to the $CO_3$ (carbonate) that leads to the formation of a weak acid ($H_2CO_3$), gypsum or PG can not since its anion $SO_4^{2-}$ (sulfate) leads to the formation of a strong acid ($H_2SO_4$).

## Aglime vs. Phosphogypsum

Research shows that PG reduces subsoil acidity leading to positive influences on plant root development. This is especially important in rainfed cropping systems, where root absorption of water and nutrients at deeper soil layers may be limited under water stress, thereby affecting plant growth. Plant roots do not grow well with elevated concentrations of $Al^{3+}$ or in Ca-deficient zones in the soil. Plant root tips need Ca for adequate elongation, but plant roots developing in deeper soil layers with limited amounts of Ca are unable to take advantage of Ca absorbed by plants in the upper soil layers because $Ca^{2+}$ does not move through the plant phloem. Because gypsum has higher water solubility than lime, it can dissolve and leach through the soil profile adding significant amounts of Ca and $SO_4^{2-}$ at depths where lime would not reach. The increase in $SO_4^{2-}$ concentration in deeper soil layers will favor its combination with Al to form $AlSO_4^+$, which diminishes the activity (and toxicity) of $Al^{3+}$. At the same time, the plant availability of Ca is increased, which favors the elongation of plant roots in the acidic subsoil. **Figure 1** is an example of the effect of Ca

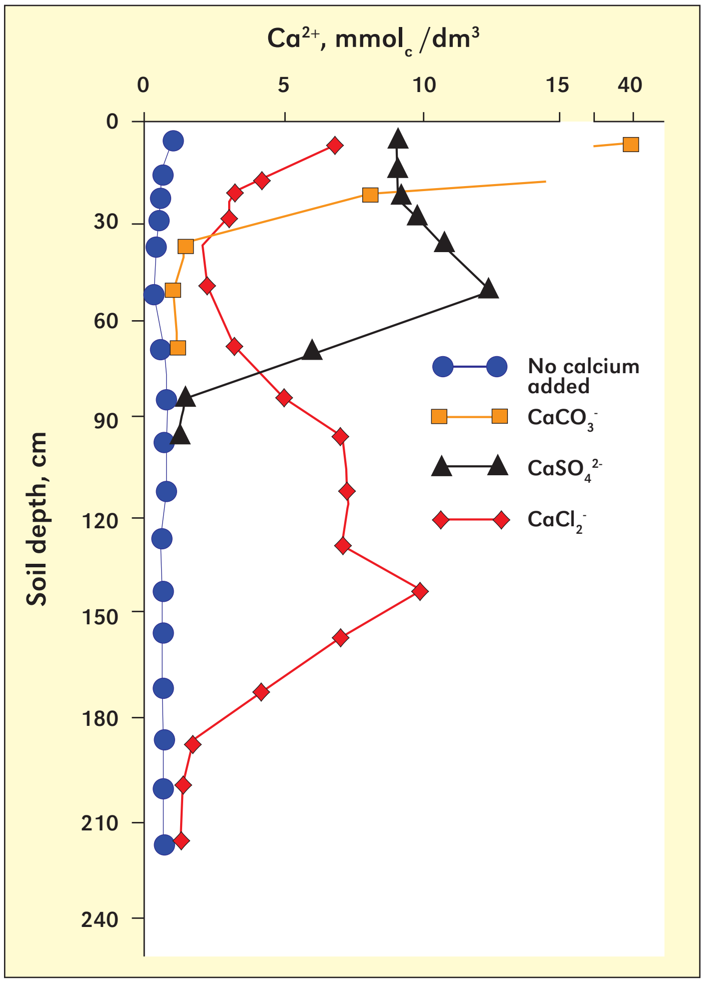
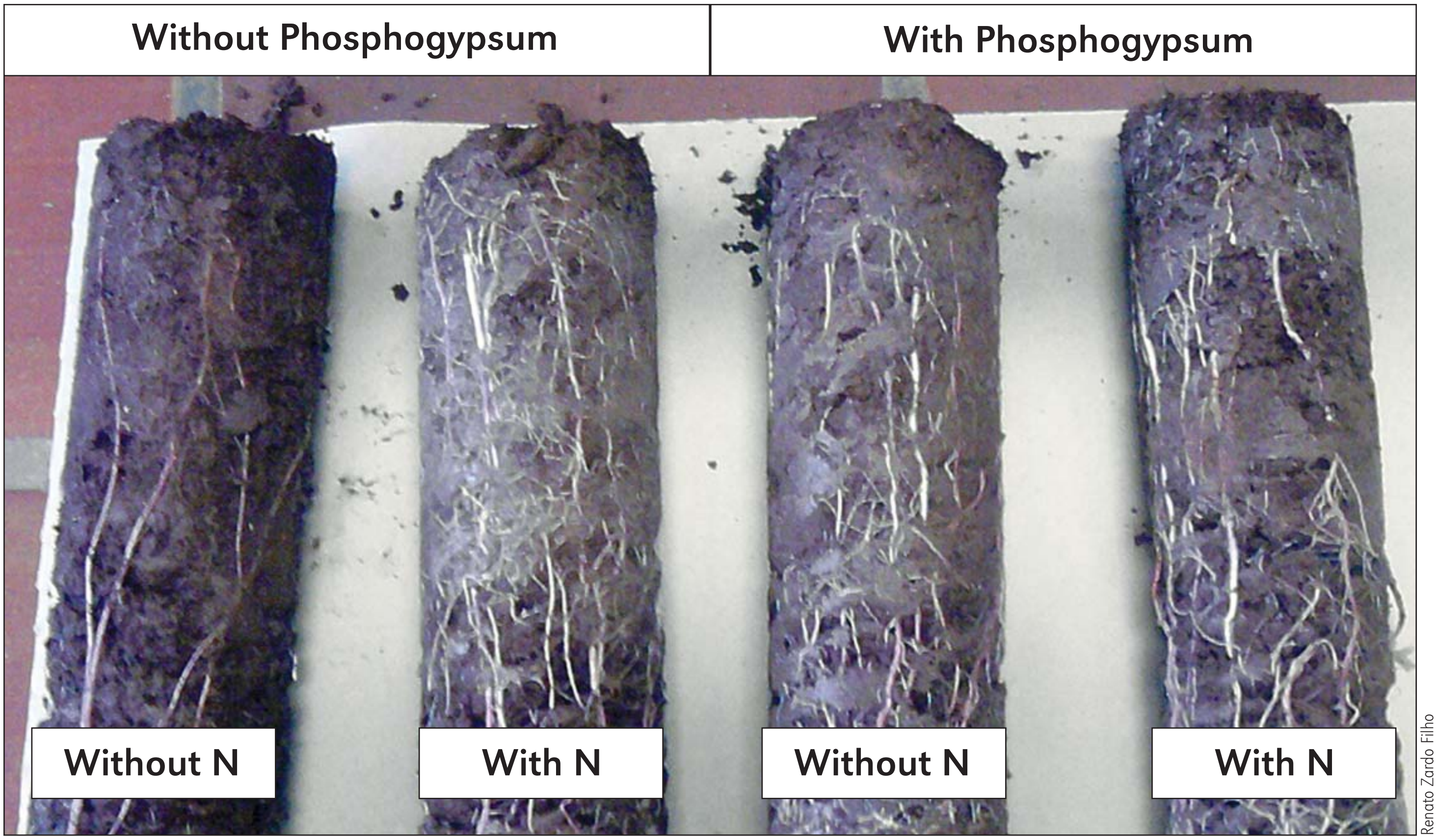



**Figure 1.** Distribution of Ca in soil layers of a Brazilian oxisol for different Ca sources after addition of 1,200 mm of water (Sousa and Ritchey, 1986).

Abbreviations and notes: N = nitrogen; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium; Al = aluminum.




**Corn root growth** at 40 days after emergence to a 50 cm depth in undisturbed soil columns as affected by phosphogypsum and nitrogen (N) applications.

leaching through the soil profile when the cation is combined with different anions ($CO_3^-$, $SO_4^{2-}$, or $Cl^-$). It is clear that for the sulfate source, $Ca^{2+}$ moves in the soil profile to a position that is available to plant roots, while the $CO_3^-$ source provides too little movement of $Ca^{2+}$, and the $Cl^-$ source provides it in excess.

Thus aglime should be used respecting the 4R approach (right source, rate, time, and place) to neutralize soil acidity within the top 20 to 30 cm of the soil surface. Gypsum or PG, also considering the 4R approach, should be used in certain soil conditions to reduce subsoil acidity. A PG product has little effect within the surface soil layer, which is critical information for farmers. When PG was first introduced in Brazil during the mid 1980s, many farmers applied it with the impression that it would have the same effect as lime. In fact, high rates of PG created a cation imbalance and limited plant growth.

## Phosphogypsum Research

A classical field trial by Ritchey et al. (1980) was key in suggesting that PG could be used to reduce subsoil acidity. The authors were in fact comparing single and triple superphosphate (SSP, TSP) as sources of P in maize with no initial goal to test PG. During one season with very little rain the researchers noticed that plants under high rates of SSP were performing much better than those under low rates of SSP or any rate of TSP. Their curiosity lead to an analysis of the different soil layers and the results clearly showed more roots and higher contents of $Ca^{2+}$, and lower $Al^{3+}$, at greater soil depths in plots where high rates of SSP were applied (**Table 1**). Pavan and Bingham (1982) also showed that $CaSO_4$ could decrease $Al^{3+}$ toxicity to plants due to the formation of a soluble $AlSO_4^+$ complex.

**Table 1.** Effect of single (SSP) and triple superphosphate (TSP) on pH, Ca + Mg, Al, Al saturation, presence of corn roots, and water content in soil layers of a Brazilian oxisol (Ritchey et al., 1980).

| Soil depth, cm | pH | | Ca + Mg, $mmol_c/dm^3$ | | Al, $mmol_c/dm^3$ | | Al saturation, % | | Roots, present or not | | Water, ml/L | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TSP | SSP | TSP | SSP | TSP | SSP | TSP | SSP | TSP | SSP | TSP | SSP |
| 0-15 | 5.4 | 5.1 | 34 | 19 | 0.3 | 3.1 | 1 | 14 | Yes | Yes | 136 | 166 |
| 15-30 | 5.0 | 4.7 | 21 | 13 | 2.9 | 5.6 | 12 | 30 | Yes | Yes | 181 | 199 |
| 30-45 | 4.6 | 4.7 | 8 | 14 | 7.1 | 3.7 | 47 | 21 | Yes | Yes | 202 | 217 |
| 45-60 | 4.1 | 4.8 | 5 | 15 | 7.8 | 2.0 | 61 | 12 | Yes | Yes | 227 | 206 |
| 60-75 | 4.0 | 4.5 | 4 | 11 | 6.5 | 2.3 | 62 | 17 | No | Yes | 236 | 208 |
| 75-90 | 4.2 | 4.6 | 2 | 8 | 5.4 | 1.8 | 73 | 18 | No | Yes | 243 | 233 |
| 90-105 | 4.2 | 4.3 | 1 | 5 | 4.0 | 1.4 | 90 | 22 | No | Yes | 250 | 232 |
| 105-120 | 4.2 | 4.4 | 1 | 5 | 2.8 | 0.4 | 74 | 8 | No | Yes | 253 | 241 |

**Table 2.** Nitrogen uptake by corn above-ground tissues and the concentration of leached $NO_3$-N as affected by phosphogypsum and nitrogen applications to soil columns (Caires et al., 2016).

| | Without N | With N |
|---|---|---|
| Phosphogypsum (PG) | Nitrogen uptake, mg/plant | |
| Without PG | 66.1 | 91.9 |
| With PG | 112.5 | 159.6 |
| Increase (%) | 70 | 74 |
| | Leached $NO_3$-N, mg/L | |
| Without PG | 7.3 | 11.4 |
| With PG | 6.8 | 6.4 |
| Decrease (%) | 7 | 44 |

These results, with additional information from the literature, especially from South Africa, inspired many Brazilian studies to follow. In one of these experiments, the use of PG showed economic viability to maximize crop grain production under a long-term no-till system (Caires et al., 2011). More recently, Caires et al. (2016) found that improved subsoil acidity due to PG in a no-till corn system also increased N use efficiency (NUE), improved grain yield, and reduced environmental risks due to $NO_3$-N (nitrate) leaching. Since PG application potentially promotes root development in deeper soil layers, application may improve NUE by increasing N uptake, especially from $NO_3$-N that readily moves to the subsoil (**Table 2**).

## Conclusion

Application of lime is no doubt the best alternative to alleviate topsoil acidity and provide conditions for adequate crop development. No other practice is as efficient and economical as soil liming. However, alternatives such as PG application might be of use under specific situations—namely managing detrimental effects of subsoil acidity. Better root growth at depth translates into more efficient water and nutrient use by plants. As with any product, PG should be applied according to the concepts of 4R Nutrient Stewardship that ensure a right source, rate, time, place combination in the field. BC

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**The abundance of research from Brazil has established good 4R management practices for the appropriate use of PG in soils. Such practices are summarized as:**

**Right Source:** Phosphogypsum should be used in accordance with country regulations. Regulations especially related to radioelement concentration are under review in many parts of the world. In Brazil, because PG originates from igneous phosphate rock, radioelement concentrations are low and not considered problematic. PG should be uniform, dried, and analyzed for Ca and S concentrations. On average, PG is expected to have 20% Ca and 15% $SO_4$-S. Transportation is the main cost consideration for PG and it can restrict its use in certain areas. In Brazil, PG use is thought to be cost effective within 500 miles of its origin.

**Right Rate:** A right PG rate is fundamental in improving subsoil acidity. Lower than necessary rates may not achieve the desired effect. Applying too much PG can lead to undesired side effects that, for example, can carry Mg and sometimes K to deeper soil layers that plant roots can not reach. For Brazilian oxisols, PG should be applied according to the following formula:

PG = clay x 50, where PG = amount of PG (kg/ha), and clay = % clay content in the (20 to 40 or 40 to 60 cm) subsoil layers.

**Right Time:** Phosphogypsum should be applied after lime reaction so PG does not limit dissolution of the lime in the soil. Phosphogypsum should be applied before crop seeding in cereal crops. For perennial crops, PG can be applied before crop establishment or anytime during the crop's lifetime, when needed.

**Right Place:** The application of PG is only recommended when analysis of deeper soil layers (20 to 40 or 40 to 60 cm) shows exchangeable $Ca^{2+}$ content < 5 $mmol_c/dm^3$, exchangeable $Al^{3+}$ content > 5 $mmol_c/dm^3$, and/or $Al^{3+}$ saturation > 20%. The product should be applied over the soil surface.

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