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Review

Enrichment of soil and its environmental impact

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ABSTRACT

Phosphorus is one of the three primary macronutrients required for the growth of plants and animals. Its excessive application in agrosystems has generated soils enriched with P in many latitudes. The review's aim is to provide an abbreviated consideration of the meaning enriched with P and its environmental effects. When the balance between the applied P minus the exported is positive, the assimilable P increases. Therefore, an accumulation of P occurs over the years, producing the P-enrichment of soils. Phosphorus participates in the eutrophication of water bodies, which is exacerbated by P-enriched soils. In P-enriched soils, the pH increases, the content of organic matter decreases, the kaolinite is decomposed, nutrition is affected by antagonistic effects, and mycorrhizal function is inhibited.

Key words: phosphorus, phosphorus in soil, eutrophication, soil fertility

INTRODUCTION

P is one of the three primary macronutrients required for the growth of plants and animals; its application is necessary to maintain the production and profitability of crops and animal production [(1)].

Due to the phosphoric applications over years with mineral fertilizers, organic fertilizers, or both, sometimes irrationally [(2)], high concentrations of P have been reached in many agricultural soils of different latitudes.

Soils with very high concentrations of P have been found in Maryland, USA [(3)], in Holland [(4,5)], in other countries of the European Union [(6)], in China [(7)], which has been attributed to a more significant contribution of the nutrient than the removal made by the harvested product [(1,8,9)].

Based on the above, the presented review aims to make an abbreviated assessment of the meaning of soil enriched with P and its environmental effects.

Phosphoric enrichment of the soil

When in an agricultural area, the balance between the applied P minus that extracted by the harvested product (exported) is positive, the phosphoric availability of the soil (assimilable P) increases, and in turn, occurs an accumulation of P in the soil (residuality), which causes the phosphoric enrichment of the edaphic environment [(10–15)], over the years, that is, the soil becomes what is called a “P-enriched soil”. In these cases, the assimilable P exceeds the value considered optimal for the crops, and these do not respond to phosphoric fertilization.

The availability of P for crops is determined, in general, from the results obtained by i) the soil analysis, ii) the analysis of the plant or an indicator tissue of the plant, iii) the balance between the P applied to and exported by the harvested product.

Soil analysis provides information on the availability of P for plants [(16–19)], while the analysis of an indicator tissue of the plant (generally leaves or part of them) provides information on the crop's nutritional status [(3,20,21)]. Both methods are valid, and the nutrient recommendation precision increases if both analyses are carried out. The balance method constitutes restoring what is exported from the field with the harvested product to the soil. For this, the chemical analysis must use the entire plant or parts [(22,23)].

The results obtained from the foliar or soil analysis are compared with already established categorizations to determine the plant's nutritional status or the soil's concentration of available P. In TABLE 1, it is exemplified with soil analysis using Bray and Kurtz No.1 [(24)], Olsen [(25, 26)], Mehlich 3 [(26, 27)] and Oniani [(28)] methods for determining assimilable P.

Table 1. Categorization of assimilable P from the soil determined by different methods

Extractive solution	Category	P, $mg.kg^{-1}$
0.03 M NH_4F +	**Bray and Kurtz No. 1**	
0.025 M HCl	Very Low	< 3
pH 3.5	Low	3 – 7
	Medium	7 – 20
	Adequate	> 20
0.5 M $NaHCO_3$	**Olsen**	
pH 8.5	Low	< 5
	Medium	5 – 10
	Adequate	> 10
	Low	< 10
	Optimum	10 – 30
	High	30 – 60
	Very High	> 60
0.2 M CH_3COOH+	**Mehlich 3**	
0.25 M NH_4NO_3 +	Low	< 15
0.015 M NH_4F +	Optimum	15 – 50
0.013 M HNO_3 +	High	50 – 100
0.001 M EDTA	Very High	> 100
	Critical Level	30
	Oniani ($mg.100g^{-1}$, P_2O_5)	
0.05 M H_2SO_4	Low	< 15
	Medium	15 – 30
	High	30 – 45
	Very High	> 45

These categorizations in most cases are referred to as Low, Medium, High and Very High, also as Very Low, Low, Medium, High and Very High, or as Very Poor, Poor, Medium, Supplied, Very Supplied, among other modalities. In short, it is variable and dependent on the analytical technique, the researcher's considerations, the edaphoclimatic conditions, the plant species, and the management.

On many occasions in the case of soil analysis, other properties are considered to specify further the corresponding assimilable P category, such as pH, texture, organic matter content, and cationic exchange capacity, among others. In the case of plant analysis, the percentage of humidity of the analyzed sample and the age of the plant at the time of sampling are often considered.

The categories defined for the phosphoric fertility of the soil and the nutritional status of the plants are associated with the dose of fertilizers to be applied, from which the one that corresponds to each specific condition is selected. Based on the difference between the applied P and that exported by the harvest (balance method), it is intended to maintain a stable state of phosphoric fertility of the soil over time (balance equal to "zero"), provided that this fertility is considered appropriate (Medium or High Category). The balance method allows increasing phosphoric fertility in soils with insufficient assimilable P (Low or Very Low) by applying more P than is exported from the field ("positive balance") until it reaches an optimal level of assimilable P concentration. A "negative balance" is appropriate to decrease the concentration in P enriched soils (Very High); the nutrient application is eliminated until the soil analysis indicates that the phosphoric category has reached an adequate level. From that moment on, the strategy will be to maintain a balance equal to “zero”.

Everything seems to indicate that there is a guarantee that in an agrosystem, the amount of P required for cultivation is applied to the soil; however, unfortunately, this has not been the case; various aspects have led to the phosphoric enrichment of the soil.

A widespread issue in agricultural practice is that the farmers are satisfied to apply more nutrient than recommended without also assessing the negative economic impact of this practice.

Applying chemical phosphoric fertilizer or some amendment with appreciable P content and organic fertilizer can also be mentioned. This behavior has been practiced for years in livestock areas, especially in developed countries [29], where livestock excreta are taken and incorporated into the fields. Still, it is almost always the same fields that receive this treatment since that the transfer of wastes from its source to areas far from it makes the production process too expensive.

Another issue that deserves to be mentioned is the usage of fertilizer formulas in agriculture. It is complex to guarantee the dose of some nutrients without exceeding the needs of another, and it is almost always P that is overestimated. Some formulas used in agriculture are:

10-10-10	17-17-17
12-12-12	21-7-14
15-15-15	9-13-17

Another way to supply P to the arable horizon of the soil is through the biogenic accumulation or the nutrient recycling, possible through the incorporation of roots, senescent leaves, branches, flowers, fruits, and harvest residues, which provide part of the P on the surface that the plant extracts from deepest horizons.

Environmental impact of the P enrichment soil

Effect on water sources: Eutrophication

Eutrophication is defined simply as the over-enrichment with nutrients of aquatic ecosystems that leads to the growth of algae and anoxic events [(2,30)] or as the process of organic enrichment or biological productivity of a body of water, accelerated by greater contributions of nutrients [(31)].

In response to over-enrichment with nutrients, phytoplankton is modified towards an annoying proliferation of algae, which, when decomposed, produces a foul odor and causes a decrease in oxygen, causing the death of the fish [(11)].

Other problems associated with eutrophication are the presence of toxins in the water, loss of water transparency and a decrease in light reaching deep, the bad taste of drinking water, the disappearance of native plants, and loss of biodiversity [(32)].

Eutrophication is also a problem in many coastal marine areas, causing the death of coral reefs.

Finally, eutrophication in both fresh and saltwater sources leads to the loss of aquatic ecosystems' aesthetic, ecological and economic values.

Many aquatic ecosystems in the world have been subjected to eutrophication (South America [(33-35)], Cuba [(36-38)], Europe [(39)], China [(40)], Australia [(41)], South Africa [(42)], India [(43)], United States [(44-45)] (Table 2).

Table 2. Examples of aquatic ecosystems affected by eutrophication

Ecosystem
Santa Lucía River, Uruguay
Titikaka Lake. Bolivia
Dam La Juventud, Pinar del Río. Cuba; dam Marenga, Ceará. Brazil
Los Guaos River, Santiago de Cuba. Cuba
Ariguanabo River, Artemisa. Cuba
Gulf of Batabanó, Mayabeque. Cuba
Baltic Sea, Black Sea, Mediterranean Sea, Northeast Atlantic. Europe
Taihu Lake, Chaohu Lake, Dianchi Lake, Yangtze River. China
Estuary Peel-Harvey, Mokoan Lake, Darling River. Australia
Reservoir Albert Falls, Reservorio Midmar, Reservoir Hartbeespoort, Coastal Lake Sibhayi, Coastal Lake Kuhlange among others. South Africa
Sukhna Lake. India
Everglades, Florida. United States
Chesapeake Bay, Mid-Atlantic region, United States

In addition to N, P is considered a critical component that limits the freshwater quality and causes eutrophication in many lakes and other water sources (2,46,47). The increase in the concentration of P in water bodies is produced, among other causes, by incorporating the nutrient through runoff that occurs in agricultural soils (48–50).

From the above, it can be deduced that to the extent that the applications of P are unnecessarily higher, the greater the risk of P enrichment soil and, at the same time, the greater the risk of participating in the eutrophication processes of the water sources. Hence, knowing how much P is required in each condition is vital to supply the nutrient that meets the requirements and no more.

Effects on the soil

It is recognized that P has low solubility and low mobility in soils, and it can only be replaced by fertilization (51,52). When phosphoric fertilizer is applied and its granules dissolve with soil moisture, reactions develop between phosphate, soil constituents, and non-phosphorous compounds in the fertilizer, which remove the nutrient from the liquid phase and make it less soluble (53). This phenomenon has been known for over a century and a half and is known as fixation or retention of P. Calcium carbonate and hydrated oxides and oxides of Fe and Al are among the soil constituents that participate in the fixation or retention of P, suggesting that P precipitates as Ca, Fe, or Al phosphate, or that it binds chemically to these cations on the surface of soil minerals (54).

The retention of P with the mentioned cations is called adsorption and is considered an exchange reaction between the phosphate ions and the hydroxyl ions associated with the metal.

As the concentration of phosphate anions rises, the exchange with the anions $(OH)^-$ increases, which elevates the density of the negative charge of the colloid and thus, the pH of the solution (55).

Concentrated solutions of P have been shown to decompose kaolinite, leading to the precipitation of an Al-P compound (56). It has also been found that the adsorption of P promotes the release of $(SO_4)^{2-}$ and $(SiO_4)^{4-}$ and pH solution elevation, indicative of the replacement of the mentioned anions and $(OH)^-$ groups. By increasing the concentration of P, there is an abrupt increase in the release of $(SiO_4)^{4-}$ and not $(SO_4)^{2-}$, which suggests that the silicate clay minerals are disorganized and the $[(SiO_4)^{4-}]$ is displaced (57).

Evidence has been presented on the solubilization of soil organic matter caused by mono and di ammonium phosphate in the microsites of application of phosphoric sources (58).

The mechanism proposed for the explanation of the behavior described above consists in that the ammonium of the fertilizers replaces several di and trivalent metal ions of the stable complexes of organic matter, thus making the formed complexes more soluble, favoring the movement of organic matter through the soil profile (59).

Faced with excess P in the soil, plants tend to show sufficient or excess P. When this occurs, the chlorophyll contents are drastically reduced due to the manifestation of antagonism with anions such as NO^{3-}, since the photosynthetic capacity and, therefore, chlorophyll is directly related to the content of P and N in the plant (60).

High concentrations of P in the soil cause a decrease in the absorption of Zn, either by the formation of precipitates in the soil or by metabolic processes in plants, which prevent the translocation of the nutrient from the root to the rest of the plant (61).

It has been shown that high concentrations of P in the soil decrease the levels of mycorrhizal colonization (62–65), lead to rapid suppression of the arbuscular development, and temporarily inhibit the growth of root colonization (66).

GENERAL CONSIDERATIONS

The need for P in agriculture is undeniable; however, its use must be rational, in correspondence with soil and plant needs.

Excessive applications of P bring about adverse situations for the environment and agricultural production.

This review has attempted to briefly illustrate the origin of soil phosphorization and its environmental impact. Eutrophication, the increase in soil's pH, the decrease in organic matter content, dispersion and decomposition of kaolinite, antagonism with other nutrients, and inhibition of mycorrhizal function are among the adverse effects.

From the preceding, it follows that it is an obligation to act efficiently in the use of fertilizers in general and phosphoric ones in particular, which, in addition to being expensive, come from exhaustible sources of nature, already very depressed.

Therefore, it is necessary to establish the best assimilable P analysis method for each condition, know the current state of the soils in terms of their phosphoric availability, update the external and internal P requirements of the crops, establish new categorizations of soil's phosphoric availability, use the balance method (input minus export) accompanied by soil analysis to be able to more precisely adjust the doses of P to apply in each condition and finally, investigate in field conditions the effects that P enrichment could have on soil fertility.

CONCLUSIONS

- Applications of phosphorus fertilizers in agrosystems in time that exceed the exports made by the harvested product cause the enrichment of the soil with the nutrient.
- The enrichment of the soil with phosphorus facilitates the nutrient to participate in eutrophication from erosive phenomena.
- High concentrations of phosphorus in the soil increase the pH, decrease organic matter content, disperse and decompose kaolinite, cause antagonism with other nutrients, and inhibit mycorrhizal function.

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