Fertiliser Technology Research Centre

Technical Bulletin: Main characteristics and agronomic performance of triple superphosphate

EXECUTIVE SUMMARY

- Prior to the advent of ammonium phosphate (MAP/DAP) fertilizers, triple superphosphate (TSP) was the main phosphorus (P) source in many agricultural regions worldwide.
- The production of TSP is relatively simple and is achieved by treating finely ground phosphate rock (PR) particles with phosphoric acid followed by granulation. This formulation performs well in storage and in the field, but has less blending partners than MAP and DAP.
- Upon application to the soil, TSP presents slightly different dissolution patterns and P diffusion behavior than ammoniated phosphates due to composition, accompanying cation and pH.
- An agronomic advantage of TSP over MAP/DAP is in the fertilization programs of legume crops, where no additional N is needed to supplement biological nitrogen (N) fixation. Additionally, an indirect nutrition effect due to the calcium (Ca) present in the TSP can be observed in Ca-deficient soils.
- Ammonium+P joint application may deliver a small agronomic advantage of MAP/DAP over the N-free TSP in certain situations. Different mechanisms involving changes in soil pH and greater root growth due to the ammonium co-applied can explain the benefits brought by this combined nutrient delivery to crops.
- Overall, despite some differences in terms of composition, granule dissolution and the reaction with soil constituents, the agronomic performance of TSP tends to be very similar to ammoniated phosphate fertilizers, assuming equal rates are applied, the method of application is comparable, and other nutrients are balanced.

BACKGROUND

Triple superphosphate (TSP) was the first high analysis phosphorus (P) fertilizer that became widely used in the 20th century and the most common P source used in the USA and other countries until the mid-1970s. Its popularity declined when ammonium phosphates (MAP and DAP) were produced with an even higher total nutrient concentration. Moreover, the cost of TSP production can be higher than MAP in some situations, making the economics for TSP less favorable (IPNI 2007). Nevertheless, TSP is still commonly used in areas where a key advantage over ammonium phosphates is the high granular P content with no nitrogen (N) present. This makes TSP desirable for fertilization of leguminous crops, such as alfalfa and soybeans, where no additional N fertilizer is needed to supplement biological N fixation. Although recent reports (e.g. Ortez et al. 2018) suggest that high-yielding modern soybean genotypes may need additional N for achieving yield potential, the N-free P sources remain the most commonly used for legumes. The overall characteristics and agronomic performance of TSP compared with other acidulated P fertilizers are summarized in this technical bulletin.

PRODUCTION AND CHARACTERISTICS

Triple superphosphate is a soluble phosphate fertilizer containing about 20% total P (44-48% P_2O_5). Besides P, TSP also contains 13-15% calcium (Ca), and a maximum of 4% residual phosphoric acid (H_3PO_4). The concept of superphosphate fertilizer production is relatively simple, involving the addition of phosphoric acid to phosphate rock (PR), which can be simplified as:

$$Ca_{10}(PO_4)_6F_2 + 14\ H_3PO_4 + 10\ H_2O \rightarrow 10\ Ca(H_2PO_4)_2.H_2O + 2HF$$

The product of this reaction is allowed to cure for several weeks while all chemical reactions are slowly completed. After curing, the product is granulated.

The water-soluble P in TSP is calcium dihydrogen phosphate, also called monocalcium phosphate (MCP, $Ca(H_2PO_4)_2.H_2O$). The water insoluble P fraction (up to 20%) includes unreacted phosphate rock, dicalcium phosphate (DCP; $CaHPO_4$ and $CaHPO_4.2H_2O$), and various complex iron (Fe) and aluminium (Al) phosphates resulting from Fe and Al impurities in the PR. The chemistry of TSP and the reaction products have been extensively studied decades ago (e.g. Lindsay et al. 1962).

COMPATIBILITY WITH OTHER FERTILIZERS

Alone, TSP has a high critical relative humidity and performs well in storage and in the field. However, because of the presence of free acid, TSP can react with other fertilizers in blends making them incompatible or a caking and dust risk. As a result, TSP has less blending partners than ammoniated P fertilizers.

SOLUBILITY, DISSOLUTION AND REACTION WITH SOIL

The water-soluble P content in TSP varies according to national legislation requirements, but it is usually higher than 80%. The water insoluble P fraction in TSP formulations is dependent on the PR grade and the acidulation process, but it can still present agronomic value as long as it is soluble in neutral ammonium citrate solution (Johnston and Richards 2003).

After application, granulated TSP absorbs soil water and dissolves leading to the release of phosphate ions into the soil solution, followed by the reaction of phosphate with soil constituents (Figure 1). Although the main acidulated P fertilizers are fully soluble in water, ammoniated and superphosphates present slightly different dissolution patterns and P diffusion behaviour due to composition, accompanying cation and pH. The main differences between P dissolution from TSP compared to other P fertilizers are discussed below:

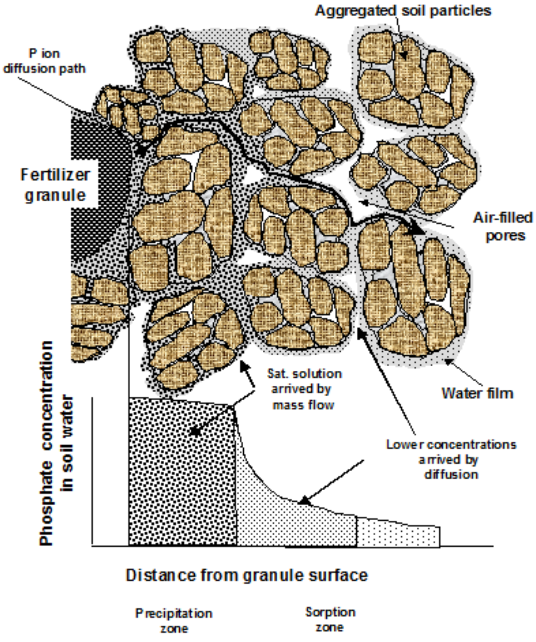

Figure 1. Diagram representing the movement of phosphate out of granules into soils (Hedley and McLaughlin 2005). Reproduced with permission of the American Society of Agronomy, the Crop Science Society of America, and the Soil Science Society of America.

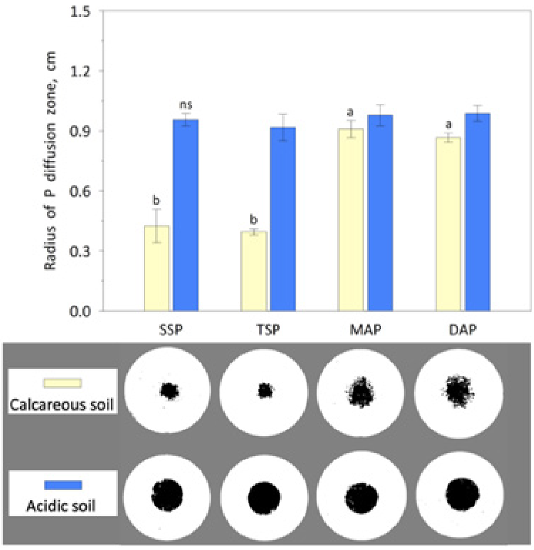

Figure 2. [Top] Radius of high P diffusion zone (cm) in a calcareous and acidic soil, 7 days after application of an SSP, TSP, MAP or DAP fertilizer granule in the centre of a Petri dish filled with soil (same amount of P applied in all cases) (Montalvo et al. – unpublished). [Bottom] Corresponding P diffusion from the granules assessed through a non-destructive visualization technique (Degryse and McLaughlin 2014). Columns labeled with different letters are significantly different at $P \leq 0.05$.

- In the residual granule and at the soil-fertilizer interface, the behaviour of P is much more influenced by the nature of salts and the chemistry of P in the granule than the chemical properties of soil. The main P compound in TSP (MCP) dissolves to form a P-enriched solution, which starts to move away from the granule, but some of the P precipitates in and around the granule. In extreme cases, the dissolution of TSP can be considerably reduced if co-applied with lime or in a highly calcareous soil. Figure 2 shows the limited P diffusion around TSP and single superphosphate (SSP) granules incubated for 7 days in a calcareous soil compared to MAP and DAP, whereas P diffusion was similar when the four formulations were incubated in an acidic soil. This is due to the Ca-common ion effect that inhibits the dissolution of Ca-containing salts when the Ca concentration in the media is high. Since MAP and DAP contain no or negligible Ca, *in situ* Ca-P precipitation is less likely, though this may still occur to some extent because of soil Ca moving into the granule carried by soil solution.

- In the zone around the dissolving granule, the composition of the near-saturated solution of the soluble P fertilizer determines the fate of the fertilizer-derived P. For TSP and MAP, the strongly acidic P solution causes the dissolution of soil constituents around the granule. The dissolution of these soil constituents may generate a solution rich in various cations. This may lead to the formation of low solubility forms of P around the residual granule, which can negatively affect P movement away from the granule. On the other hand, DAP initially forms a solution with a high pH (approximately 8), which favours the formation of Ca and magnesium phosphates.

- In the outer P unsaturated zone, movement of P is governed by diffusion, hence it is the soil P sorption characteristics, not the fertilizer formulation, that plays a major role affecting the fate of fertilizer-derived P. Thus, the fertilizer-derived P is subject to the same processes, regardless of the fertilizer type.

AGRONOMIC PERFORMANCE

Overall, most researchers and agronomists agree that there is little difference (if any) in the agronomic performance of ammoniated and superphosphates. These sources tend to perform similarly when equal rates are applied, the method of application is comparable, and other nutrients are balanced. Hence, on a "per unit P" basis, the selection of acidulated P fertilizers depends more on the farmer preference, the crop, the economics, the application method and the combination of nutrients required.

In some instances, an agronomic advantage of TSP over ammoniated phosphates is observed. The most noticeable case where TSP may be a better choice than ammoniated phosphates is on legume crops, as legumes do not require N and TSP is a N-free high-analysis P source. External addition of mineral N can decrease nodulation and the contribution of biological N fixation to N uptake, with no further gains in yield (Hungria et al. 2006). In other cases, the Ca added through TSP can provide nutritional benefits in Ca-deficient soils, as clearly demonstrated by Montalvo et al. (2015), who reported that wheat dry matter was threefold higher for TSP-treated plants than for the treatments with MAP (granular and fluid) and DAP in a Ca-deficient Chilean Andisol (Figure 3). Another possible advantage related to the N-free status of TSP is the lower toxicity risks in high pH and calcareous soils when compared to DAP, which may cause seedling injury and root growth inhibition through ammonia (NH_3) when placed too close to the seed (Openshaw 1970).

On the other hand, ammonium phosphate formulations offer the advantage of N+P joint application, while TSP has restricted blending partners as this fertilizer is not suitable to be blended with urea, the main N source used in agriculture. Although joint application of N+P may not always translate into enhanced agronomic performance compared to separate applications, both P availability and yield can be increased when N is co-located with the P source (Olson and Dreier 1956; Grunes 1959; Miller et al. 1970). Engelstad and Allen (1971) used conventional and split-root pot trials to assess N and P placements effects. The uptake of P was enhanced when the N sources were applied in the P band, at all levels of applied P, pointing to benefits of N+P co-location. When N was applied 2.5 cm away from the P band, it did not affect P uptake. Blair et al. (1971) reported higher P concentration and shoot dry matter due to the co-application of P + N (as NH_4^+) to corn seedlings (Figure 4). These authors explained the increased P use by corn due to the reduction of pH at the soil-root interface when NH_4^+ ions were absorbed. Increased root mass around the granule due to concomitant N supply is also thought to be responsible for an increased crop P uptake. Ammoniated phosphates may also be more effective than TSP in highly calcareous soils, due to limited dissolution of the TSP granules through the common (Ca) ion effect described above (Degryse et al. 2013), but there is no extensive field agronomic evidence to suggest this is expressed widely in crop yields.

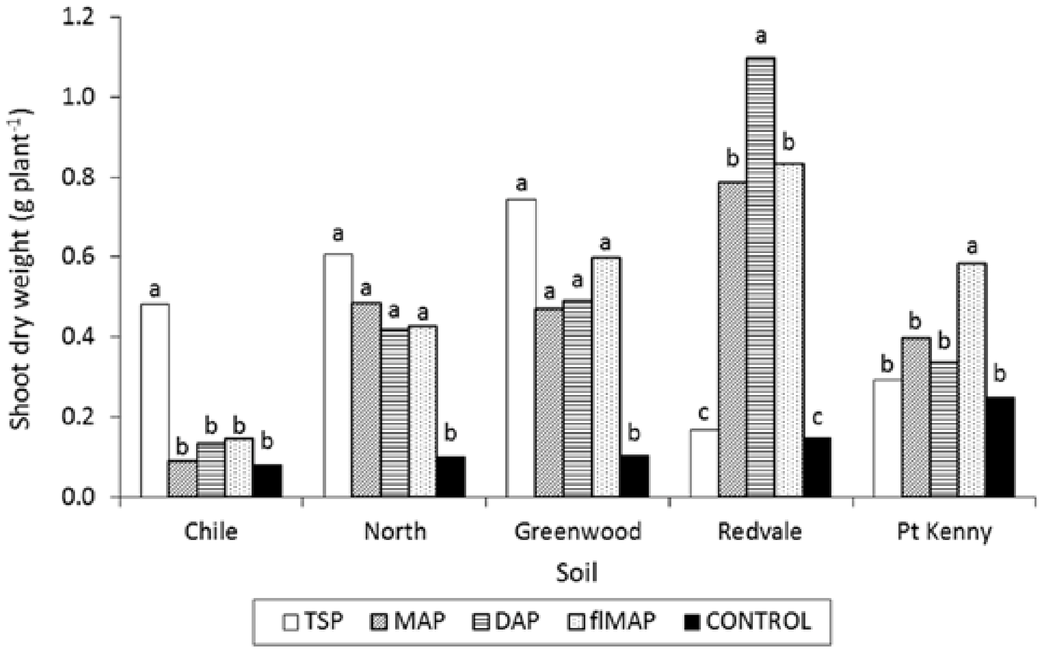

Figure 3. Shoot dry matter yield of wheat grown in five contrasting soils treated with granular TSP, MAP, DAP or fluid MAP fertilizers (Montalvo et al., 2015). Columns labeled with different letters are significantly different at $P \leq 0.05$. Reproduced with permission of the Soil Science Society of America.

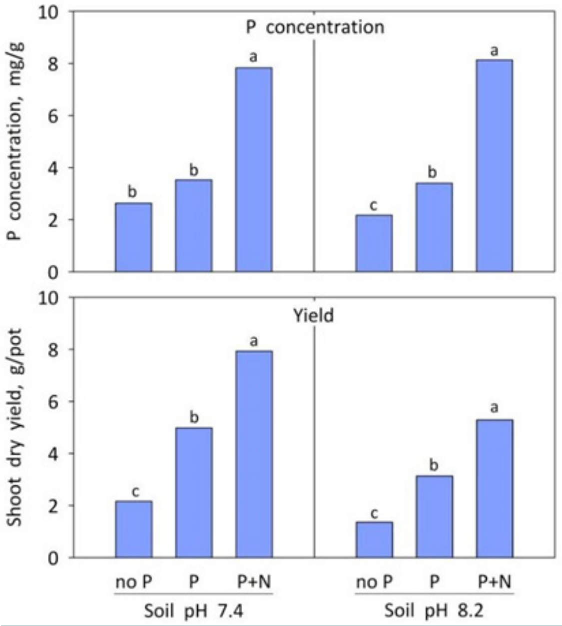

Figure 4. Influence of P and N (as NH_4^+) additions in two soils on P concentration and corn dry yield. Prepared from the data published by Blair et al. (1971). Columns labeled with different letters are significantly different at $P \leq 0.05$.

CONCLUSIONS:

In conclusion, some differences are observed in the behaviour of P around the granule in soil, but this has little effect on P dissolution and diffusion, except in highly calcareous soils. The agronomic performance of TSP is very similar to other water-soluble phosphate fertilizers when other nutrients are balanced and the application method is the same. The scientific knowledge gained decades ago still adequately explains TSP production, dynamics and performance in soils. There have been no new advances in the science of TSP behaviour in recent years.

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Further information

The Fertiliser Technology Research Centre was established in 2007 via a partnership between The University of Adelaide and The Mosaic Company. The centre has expertise in soil chemistry, fertiliser technology and plant nutrition. Specifically, in developing novel fertiliser formulations, advanced isotopic and spectroscopic investigations of fertiliser efficiency, and field scale agronomy trials.

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