

The value of phosphorus fertilisation and microbial inoculants

Phosphorus fertilisation and microbial inoculants improve citrus nutrition and microbiology in alkaline soils. By Pieter Raath, Vivian White and Marli Vermooten (all from Citrus Research International)



Opsomming

Resultate in hierdie een-jaar-proef het getoon dat ten spyte van P-vaslegging in hoë pH-gronde, plantbeskikbare P by voldoende vlakke is wanneer die P-konsentrasie in die grond hoër is as die minimum norm; dit beteken dat verdere P-bemesting onnodig is. Toediening van P-bemesting het ook die stabiliteit van die grondbiologiese gemeenskap in die kort termyn versteur, soos geïllustreer met behulp van beide die nematode profielbeskrywings (fauna profiel/grond se voedselweb) en ensiem-aktiwiteitmetings (sogenaamde Alteration Index 3).

Summary

Results obtained from this one year trial elucidated the fact that despite P-fixation in high pH soils, P-availability was sufficient when the concentration in the soil exceeded the minimum norm; therefore, annual P-fertilisation is not required. Furthermore, application of P-fertiliser negatively impacted the soil's biological stability in the short term, as expressed by both nematode profile descriptions (Faunal Profile/Soil Food Web) and enzyme activity measurements (Alteration Index 3).



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Various soil factors affect the availability of phosphorus (P), with soil pH being critically important. In alkaline soils ($pH_{KCl} > 6.5$), the appreciable calcium concentrations result in calcium fixation of P to form insoluble $Ca_2(PO_4)_3$ (Coetzee 2007). Given the difficulty of reducing soil pH, especially where free lime is present (Saayman 1981), management of P-nutrition of citrus trees is complex in alkaline soils. Consequently, accepted soil P-norms are not regarded as reliable to guide fertilisation. Soil analyses done using Bray II extractions have revealed that many citrus orchards in regions with high soil pH have elevated P-content. This is as a result of annual P-fertilisation to counteract possible P-fixation occurring in these soils. Fertilisation is usually done in excess of the crop's requirement, resulting in progressive build-up of P in the soil.

A recent study in the Orange River region revealed that, in high pH soils with high concentrations of Bray II extractable P, sufficient P is available for uptake to avoid deficiencies without any P-fertilisation (White, 2018). Due to the detrimental effect that excessive P-concentrations in the soil have on Zn- (Coetzee 2007) and K-nutrition

(Saayman 1981), soil microbial life (Mengel & Kirkby 1982), and eutrophication of water sources (Follet et al. 1981), continuous build-up of soil P by superfluous P-fertilisation should be avoided. As a result, innovative ways to increase P-availability, both from the labile pool of "accumulated P" and annually applied P, with the goal of reducing fertiliser inputs, are required.

In a one-year trial, the use of double superphosphate and microbial inoculants was investigated to see if soil microbial activity, as well as the availability and uptake of P in high pH soils can be enhanced. The trial was also used to establish which method of soil microbiological description is most suitable to assess the impact of specific farming interventions on the soil microbial ecosystem.

Materials and methods

Treatments as described in Table 1 were applied to 'Washington' Navels grafted on Carrizo Citrange (*Poncirus trifoliata* x *Citrus sinensis*), spaced at 3 x 6 m established in Addo on a deep Augrabies soil form, with high clay (20%) and average soil Bray II P-content (379 mg P kg⁻¹) and moderate

soil Carbon (C) (1.05%).

Soil total and Bray II extractable P were determined prior to P-fertiliser application and four weeks after treatments commenced. Similarly, total activity of aerobic soil organisms, as well as those involved in P and N mobilisation/mineralisation, were determined using an enzyme assay (i.e. urease, phosphatase and β -glucosidase activity), as described in Meyer et al., (2014). In addition, the Alteration Index Three (AI3) that quantifies the balance between the three microbial-secreted soil enzymes, and is also sensitive to alterations in soil characteristics caused by management practices, was determined for each treatment (Adentunii et al., 2017). Soil biological diversity and health were assessed using the nematode profile method. From this the maturity index (MI), expressing the degree of biological stability of a soil as deduced from the number of different species of nematodes, was determined (Ferris et al. 2001). Results obtained from this agreed with findings using the AI3 values; these results are therefore not shown and discussed.

Table 1. Soil applied treatments of a Washington Navel/Carizzo Citrange block in Addo

Treatment	Description *
Control Spread	Control - P-fertilisation was spread out in the tree row.
Control Strip	Control - Strip applied P-fertilisation only.
AllGrip Spread	P-fertilisation and All-Grip®, spread out in the tree row.
iNmass Spread	P-fertilisation and iNmass®, spread out in the tree row.
AllGrip Strip	P-fertilisation and All-Grip®, strip applied at each tree.
iNmass Strip	P-fertilisation and iNmass®, strip applied at each tree.
AllGrip+iNmass Strip	P-fertilisation and All-Grip® with iNmass®, strip applied at each tree.

* A once-off application of 40 kg P ha⁻¹ (double super phosphate) was applied in September 2018. It was either spread out in the tree row, or strip applied. Application of the abovementioned soil microbial inoculants was then on top of the fertiliser, followed up by two additional applications in December 2018 and March 2019.

All-Grip®: A commercial product that contains specific strains of Bacillus and Pseudomonas spp. iNmass®: A commercial product that contains specific strains Bacillus and Azospirillum.

Various soil factors affect the availability of phosphorus, with soil pH being critically important.

Results and discussion

Given the soil's originally high soil P-concentration, double super phosphate applications of 40 kg ha⁻¹ did not cause a significant increase in plant available P (Bray II-extracted) of the topsoil (0 - 30 cm). This is ascribed to rapid P-fixation in high pH-soils. The soil's total P-concentration, however, increased to reflect the P-applications, especially in the strip applied application. Leaf samples, collected from spring flush one month after inoculant application, showed increased leaf P concentrations only for the AllGrip+iNmass Strip treatment. However, all treatments, including the control, maintained sufficient (0.11 - 0.14) to excessive (>0.18) leaf P-concentrations. This shows that the trees had an ample supply of P despite progressive fixation shortly after the September application.

β-glucosidase is the most widely used enzyme for indicating soil quality (De Almeida et al., 2015). Its activity is mainly involved in C-cycling and is greatly dependent on substrate supply (Adetunji et al. 2017). Enzyme activities of both phosphatase and β-glucosidase (Figure 1) were temporarily increased after treatment with biological inoculants. However, after October 2018 a decrease in activity was observed. Despite the much reduced β-glucosidase activity measured in the April 2019 samples, three of the strip-applied treatments (AllGrip Strip, iNMass Strip and Allgrip+iNmass Strip) showed higher activity

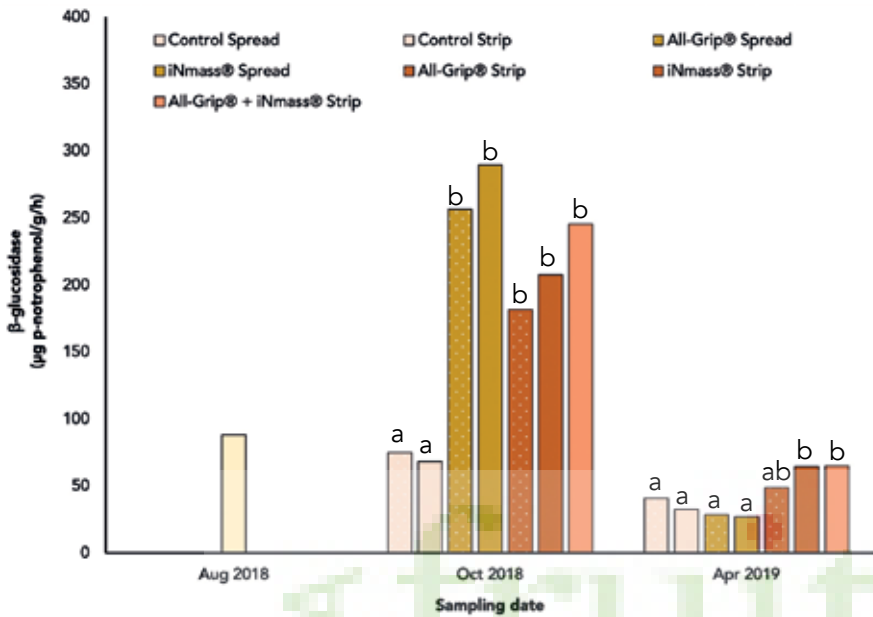


Figure 1. β-glucosidase activities of soils that received a once-off application of 40 kg P ha⁻¹ in September 2018, followed by a treatment of the soil with two soil inoculants. Values designated by the same letter do not differ significantly (p ≤ 0.05).

than the other treatments, although not significantly for AllGrip strip applied. This is ascribed to the concentrated nature of the applications. It can therefore be concluded that both All-Grip® and iNmass®, and especially combined, have positive effects on β-glucosidase activity in soil - mainly in the short term and especially, if applied at high enough rates. The combined effect of the treatments on soil biology showed a major shift in the AI3 values compared to pre-application values. All treatments containing inoculants showed higher AI3 values in Oct 2018 than the reference sample taken in Aug 2018. According to Meyer et al. (2014), higher values suggest a disturbance in soil biology, leading to imbalanced populations. However, six months later (April 2019), the AI3 was lower than the previous sampling dates, indicating that the soil inoculants did not maintain their impact on soil biology.

Conclusion

Despite the exploratory nature of this single-season trial, some general remarks

can be made. P-availability is more than sufficient when the Bray II extractable P exceeds 300 mg P kg⁻¹. Therefore, annual P-fertilisation is not required. Phosphorus application negatively affected the soil's biological stability as reflected in enzyme activities and relationships. This effect is however short lived, indicating that soil biology tends towards equilibrium. Similarly, microbial inoculants increased soil enzyme activity in the short term but despite repeated inoculant applications and the soil organic C exceeding 1.0 %, it was not sustained. Given the complexity and instability of the soil microbiological environment, as well as the many factors that affect it, analogous replication of the treatment outcomes cannot be expected in all environments. These complexities reiterate the lack of value obtained from focussing on management of soil biology, especially at the cost of long-term proven practices that are known to ensure tree and soil health (e.g. proper irrigation management and responsible tree nutrition).

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According to soil analyses done using Bray II extractions, many citrus orchards in regions with high soil pH have elevated phosphorus content.



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