# An Exploration of Circular Phosphorus for Soilless Greenhouse Horticulture

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## 1 Objectives

Soilless greenhouse horticulture is highly nutrient-efficient, but relies on pure and soluble inorganic fertilisers from finite natural reserves.
What is required to move from linear to circular phosphorus (P)?

We explore three aspects of circular P for high-tech greenhouse horticulture:
1. Available P-rich **side-streams** in the Netherlands;
2. P-recovery **technologies** and the applicability of recovered **products** (some of which are insoluble) in fertigation systems;
3. The risks of **contaminants** from circular fertilisers.

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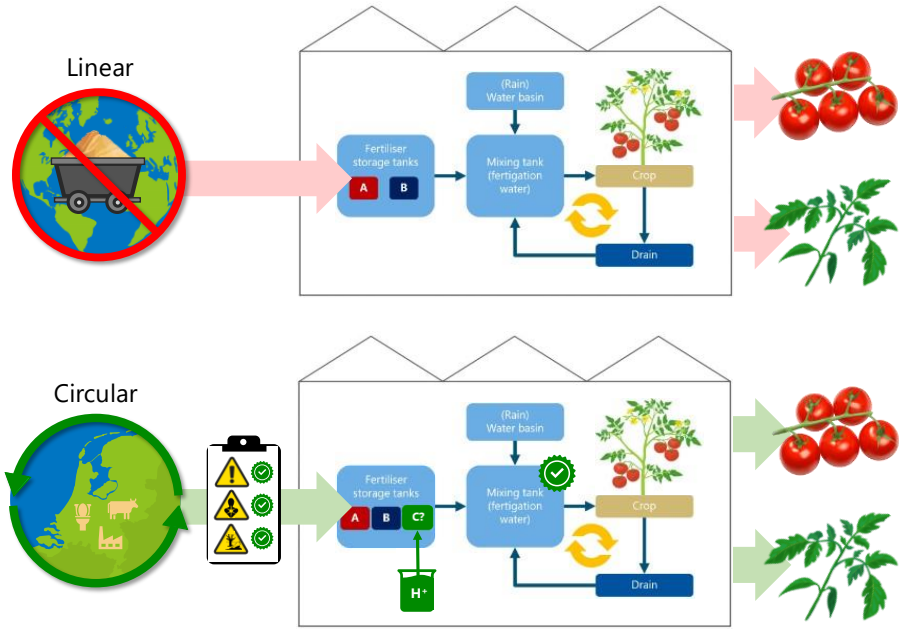
# 2. Materials and Methods

***Side-streams*** Survey using literature.

***Technologies/products*** Insoluble P products (struvite, calcium phosphates), were dissolved in a so-called 'C' tank with nitric acid, using simulated chemistry analysis. The effects of this on the nutrient recipe were calculated.

***Contaminants*** Calculation for tomato, assuming 100% accumulation of contaminants in (1) fertigation water (2) fruits or (3) residual biomass and compared this to existing limits for each of these three sinks.

***Figure 1***: A graphical abstract of the approach taken in this study. When moving from linear P to circular P, which side-streams are available? Does the fertigation system need to be changed for insoluble products? How can contaminant risks be ruled out before circular P fertilisers enter the system?



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# 3. Results and Discussion

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***Side-streams*** Enough local side-streams exist to cover greenhouse horticulture's P demand, with a trade-off between price and P concentration (Figure 2).

***Technologies/products*** A 'C' tank with nitric acid resulted in an N:P ratio of between 0.1 and 2, depending on the product. Struvite and $Ca(H_2PO_4)_2$ have minimal effects on the recipe, with other calcium phosphates resulting in ~1 mmol $l^{-1}$ more $Ca^{2+}$ in the recipe.

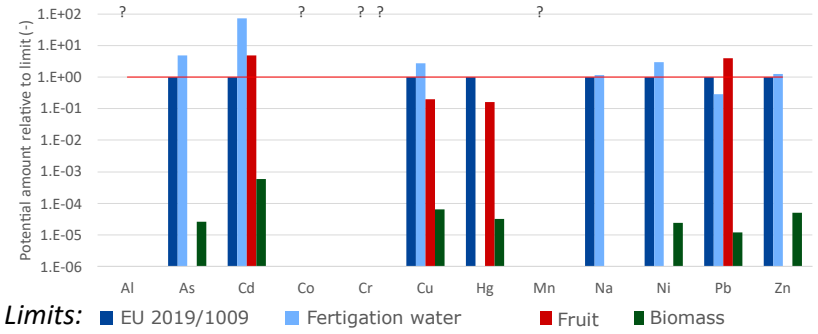


***Figure 3***: Calculated contaminant contents relative to limits, assuming a fertiliser meeting 'bare minimum' EU FPR requirements.

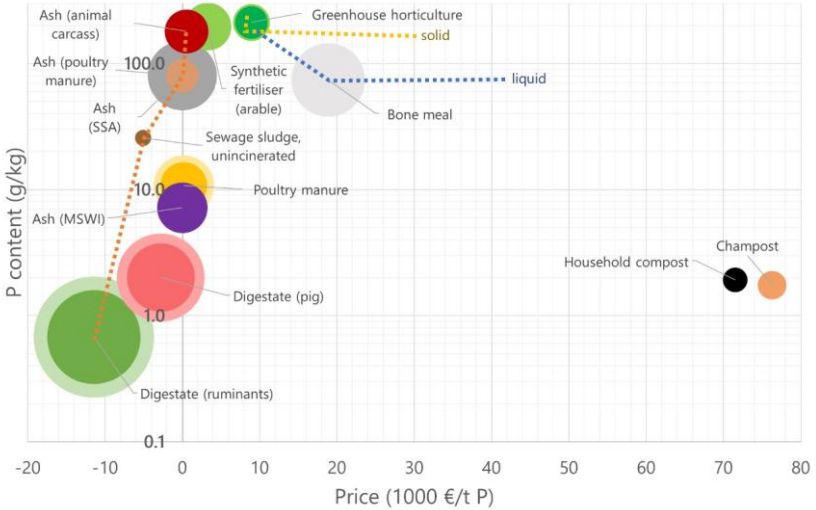


***Figure 2***: An overview of Dutch P side-streams, where $g_P$/kg is on the vertical axis (logarithmic) and price (€/$t_P$) on the horizontal. Size of the circles corresponds to total P per year.

***Contaminants*** Fertigation water is the most restrictive sink, and in some cases the fruits. Dividing the accumulation by the limit (Figure 3) shows soilless systems to often be far more sensitive than the EU FPR (2019/1009)'s minimum requirements. Na limits are only slightly higher than the FPR, but that is because tomatoes are relatively tolerant.

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# 4. Conclusions and Perspectives

> **A third** of the Netherlands' synthetic P fertiliser goes to greenhouse horticulture. Enough side-streams exist nationally to cover this demand.

> Thanks to its economic intensity compared to arable farming, **greenhouse horticulture may be a good market for recovered P products** until costs decrease.

> Fertigation systems require fully soluble fertiliser, but **insoluble products like struvite and calcium phosphates can be used** if dissolved in acid first, using an additional tank. This has a small effect on the nutrient recipe.

> To rule out contaminant risks, **products require specifications that are often far more stringent** than the EU FPR (2019/1009). Many products already come close to these requirements. Sodium is important to monitor, especially for crops more sensitive than tomatoes.


## Acknowledgements

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