An Exploration of Circular Phosphorus for Hydroponic Greenhouse Horticulture

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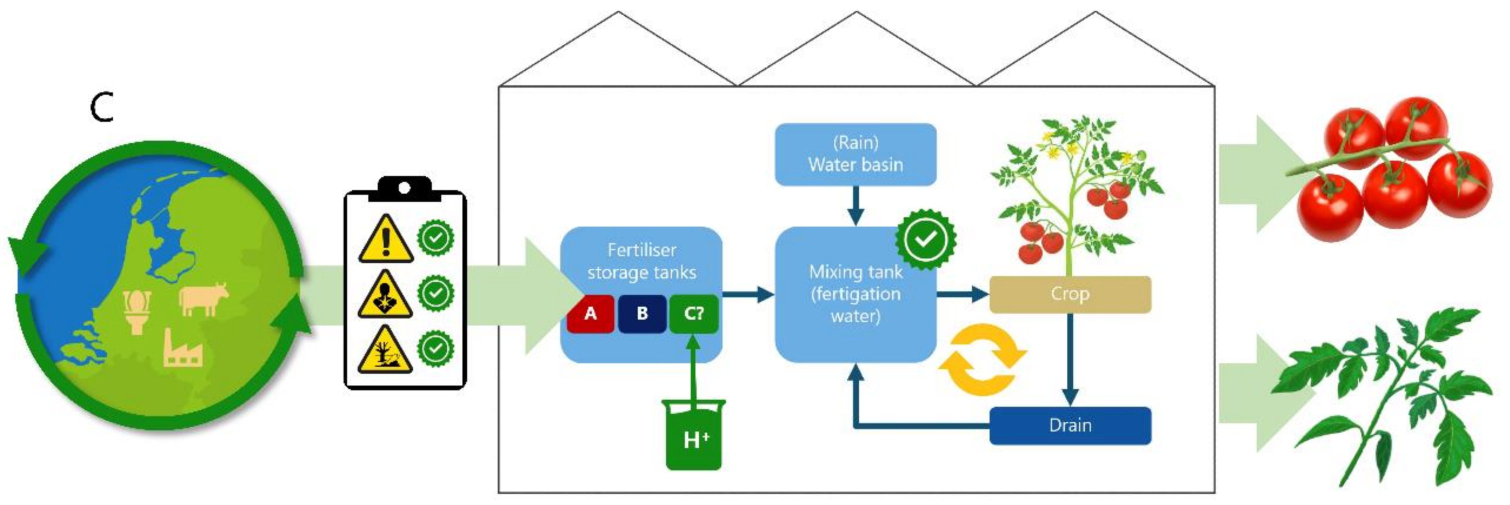
Background

High-tech greenhouse horticulture is the most nutrient-efficient form of plant production, due to its recirculating fertigation systems. However, this efficiency relies on pure and soluble inorganic fertilisers from finite natural reserves, including phosphorus (P). Whilst many studies have been done on sustainable P for open-field arable farming, studies related to the unique requirements of high-tech greenhouses are lacking.

Objective

We explore different routes for circular phosphorus for high-tech greenhouse horticulture. Three aspects are covered:

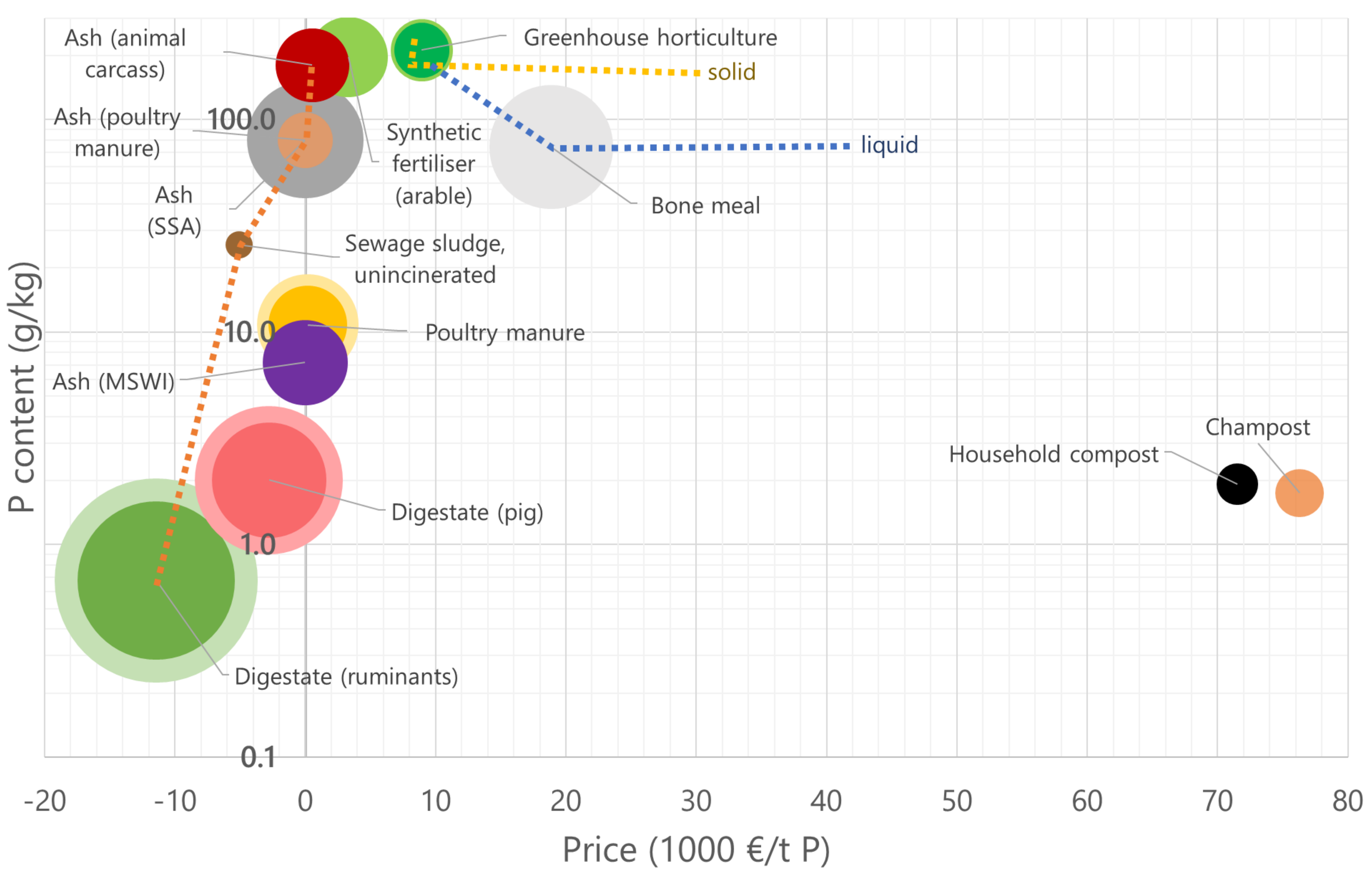
1. available P-rich **side-streams** in the Netherlands;
2. P-recovery **technologies** and the applicability of recovered **products** (some of which are insoluble) in fertigation systems;
3. the risks of **contaminants** from circular fertilisers.



A simplified diagram of a recirculating fertigation system in a high-tech greenhouse, with considerations taken in this study for circular P. Contaminant levels need to be checked by manufacturers. If fertilisers are insoluble, a third ‘C’ tank is needed, to which acid is added.

Side-Streams

Suitable side-streams are manures, ashes, and sewage sludge. There is a trade-off between P concentration and price. Fertilisers used in greenhouse horticulture show a large variation in price, and are costlier per kg P than synthetic fertiliser used in arable farming.



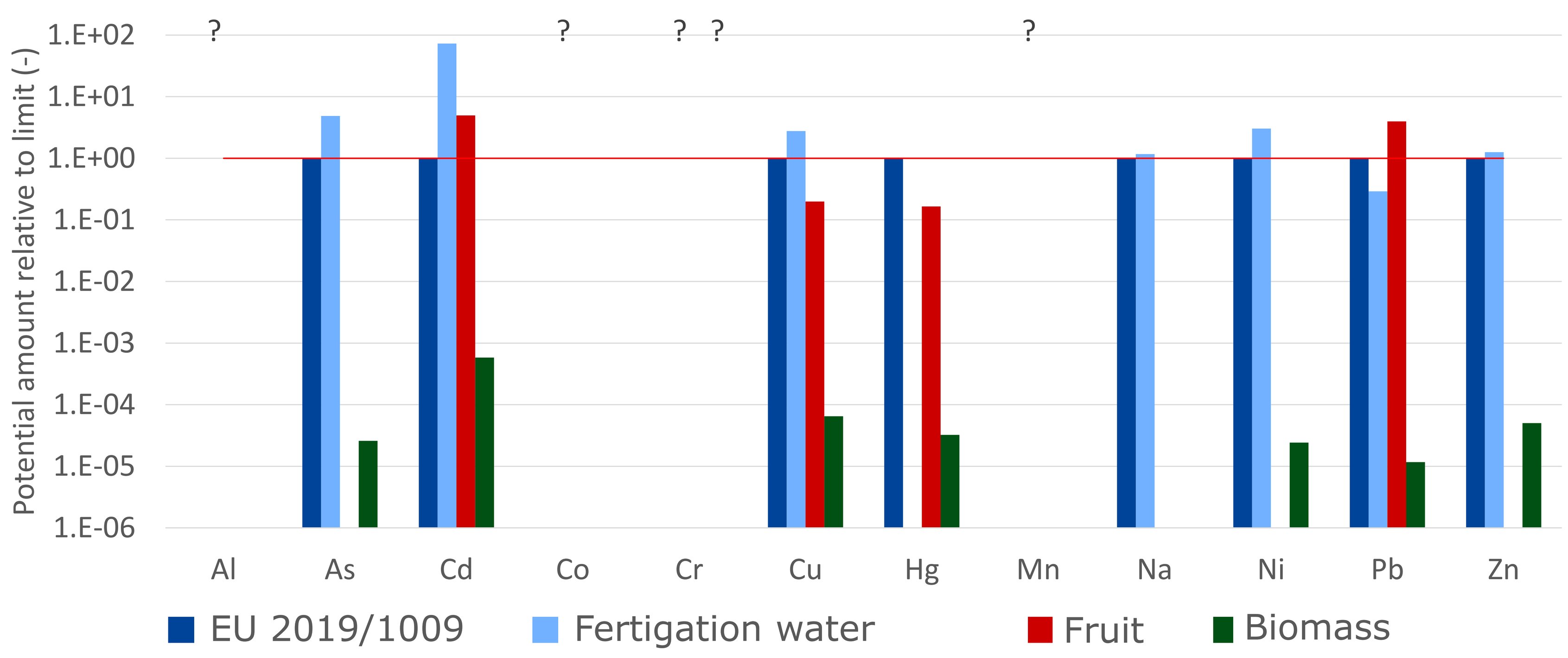
P-rich side-streams in the Netherlands. Vertical axis (logarithmic): P concentration. Horizontal axis: price. The size of the circles corresponds to the annual amount of P (2500 t for greenhouse horticulture). The Pareto front is in orange. Negative prices reflect disposal costs.

Technologies and Products

Wet chemical leaching can produce H_3PO_4, which is soluble and therefore directly applicable in fertigation systems. However, many products are insoluble precipitates: struvite and calcium phosphates. Using simulated chemistry analysis, we found these can be dissolved in nitric acid on-site (in a so-called ‘C’ tank), at a pH of between 2.8 and 3.3, resulting in an NO_3^-:P ratio of between 0.1 and 2.1. Mixing the three tanks produces a mixture that is nearly the same as the nutrient recipe, and in some cases identical, depending on the product.

Evaluation of Contaminant Risks

Our methodology assumed a worst-case scenario in which 100% of a contaminant accumulated in one of three places: (1) fertigation water (phytotoxicity), (2) fruits (human health) and (3) biomass like leaves and stems (composting requirements). Each of these three contaminant level requirements was translated back to criteria for fertiliser products. These criteria are far stricter than the EU Fertilising Products Regulation (FPR) (2019/1009). This is mostly due to fertigation water requirements, but in some cases fruits as well.



How contaminant levels, in a fictitious inorganic fertiliser (21% P) meeting the bare minimum of the EU FPR, compare to the requirements found in this study for tomato. Other crops may be stricter. The vertical axis (logarithmic) shows the score divided by the threshold; hence scores must be below 1. Al, Co, Cr and Mn have no limits in the FPR, hence the question marks.

Conclusions

- A third of the Netherlands’ synthetic P fertiliser goes to greenhouse horticulture. Enough side-streams exist locally to cover this demand.
- 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.
- The synthetic P fertilisers used in greenhouse horticulture are more expensive than those used in arable farming, meaning greenhouse horticulture may be a good first market for recovered P products until costs decrease due to economies of scale and improved technology.
- To rule out contaminant risks in greenhouse horticulture, products require specifications that are far more stringent than the EU FPR.

Acknowledgements

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