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MARSCHNER REVIEW

Past, present and future of organic nutrients

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Abstract
Background Slowing crop yield increases despite high fertiliser application rates, declining soil health and off-site pollution are testimony that many bioproduction systems require innovative nutrient supply strategies. One avenue is a greater contribution of organic compounds as nutrient sources for crops. That plants take up and metabolise organic molecules ('organic nutrients') has been discovered prior to more recent interest with scientific roots reaching far into the 19th century. Research on organic nutrients continued in the early decades of the 20th century, but after two world wars and yield increases achieved with mineral and synthetic fertilisers, a smooth continuation of the research was not to be expected, and we find major gaps in the transmission of methods and knowledge.
Scope Addressing the antagonism of 'organicists' and 'mineralists' in plant nutrition, we illustrate how the focus of crop nutrition has shifted from organic to inorganic nutrients. We discuss reasons and provide evidence for a role of organic compounds as nutrients and signalling agents.
Conclusion After decades of focussing on inorganic nutrients, perspectives have greatly widened again. As has occurred before in agricultural history, science has to validate agronomic practises. We argue that a framework that views plants as mixotrophs with an inherent ability to use organic nutrients, via direct uptake or aided by exoenzyme-mediated degradation, will transform nutrient management and crop breeding to complement inorganic and synthetic fertilisers with organic nutrients.

Keywords Sustainable agriculture · Organic nutrients · Nitrogen · Phosphorus · Plant nutrition

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Introduction

We review how practises and knowledge of plant nutrition have changed over two centuries, from the application of organic residues in early agriculture to today's predominant application of mineral and synthetic (urea) fertilisers in high-production cropping. In recent decades, organic nutrients have been recognised as nutrient sources of plants in natural ecosystems and questions have been raised about what we know about the form in which nutrients such as nitrogen (N) enter roots (Näsholm et al. 2009). To consider organic