Bio-effectors for alternative plant nutrition strategies: practical aspects for successful applications in crop production

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INTRODUCTION

Due to their potential for mineralization and mobilization of soil mineral nutrients, stimulation of root growth, suppression of pathogens and protective functions in stress defense, the investigation of perspectives to use microbial and non-microbial bio-effectors (BE) for agricultural applications has a long history. Clear effects on plant growth promotion under controlled conditions demonstrate the principle effectiveness of many BE products but performance under field conditions is frequently biased by limited reproducibility, indicating a strong influence of environmental factors. Accordingly in more than 150 pot and field experiments conducted within the BIOFECTOR project with tomato, wheat and maize and more than 30 different BE products, providing more than 1100 data sets on plant growth, yield and nutritional status, significant BE effects have been recorded only in 30% of the cases.

Factors limiting plant BE interactions

Particularly on agricultural soils, high soil fertility was frequently a limiting factor, leaving only a small response window for additional effects of BE applications. On the other hand, particularly for microbial BEs, no or even negative responses were recorded on soils with low nutrient availability (e,g, low P soils); and in these cases at least a moderate fertilization of 50 mg available P per kg soil (in pot experiments) was required to increase the probability of positive responses (Lekfeldt et al., 2016; Thonar et al., 2017). In general, all stress factors strongly limiting root growth and activity also had detrimental effects on successful establishment of plant-BE interactions, since under these conditions the host plants were obviously too weak to support the microbial BEs during the root colonization process. Accordingly, in comparison to agricultural crops, more reproducible results were recorded for tomato as horticultural plant, where at least the BE establishment phase is usually conducted under controlled and protected conditions during nursery culture of the plants.

Rhizosphere competence and Inoculation Strategies

Various experiments demonstrated that the rhizosphere competence and the colonization efficiency of microbial BEs plays a central role in the successful establishment of plant-BE interactions, although in some cases also inoculation with heat-inactivated strains exerted plant growth-promoting effects. This may reflect the activity of heat-stable signal compounds and/or indirect effects via interactions with the soil microbiome, which had been repeatedly demonstrated as transient effects after BE-inoculation. Colonization of plant roots by microbial BEs can be strongly

influenced by the inoculation technique and inoculum density. Tracing experiments under lab and field conditions revealed that seed treatments are cheap but usually the least efficient method, while soil drenching revealed the highest colonization rates and is easily performed for inoculation of small soil volumes in nursery pots or in drip irrigation systems. However, in agricultural production systems with crops of lower economic value, BE inoculation of larger soil volumes is frequently too expensive. Cost-benefit analyses for wheat showed that according to the current BE prices, even seed dressing would hardly represent an economic option. Therefore, alternative inoculation strategies using concentrated, localized BE applications close to the roots with granulated or liquid formulations for cost-saving integration into common fertilizer placement strategies, such as underfoot placement or depot fertilization, have been developed for selected *Bacillus*, *Pseudomonas* and *Trichoderma strains*, tolerant to higher fertilizer concentrations. This was associated with improved root colonization and stimulation of root growth in the fertilizer depot zone, both, in pot and field experiments but still sensitive to abiotic stress factors, such as drought and temperature extremes (Nkebiwe et al., 2016).

Mitigation of abiotic stress

Therefore, special emphasis was placed on strategies for abiotic stress mitigation to strengthen the host plant and to promote plant BE-interactions. In this context, interactions between selected seaweed/plant extracts or stress-tolerant microbial BE strains and fertilization strategies related with stress mitigation, have been investigated (fertilization with micronutrients and stabilized ammonium) under conditions of drought, salinity and cold stress (Bradáčová et al., 2016, Viscardi et al., 2016). Synergistic interactions were detected in terms of a complementary activation of stress defence lines, comprising maintainance or stimulation of root growth, detoxification of reactive oxygen species, accumulation of protective solutes, improved (micro-) nutrient acquisition and normalization of disturbed hormonal balances, partially detectable as priming effects already prior to the onset of the stress treatments. Field testing for cold tolerance during early growth of maize and for winter-hardness of wheat, revealed average yield effects of +16-17% in six out of seven trials.

BE-fertilizer interactions

Particularly, stabilized ammonium fertilization further supported BE-mediated solubilization of sparingly-soluble soil P sources and inorganic recycling fertilizers via root-induced rhizosphere acidification, increased root hair formation, stimulation of bacterial auxin production and promotion of root colonization by selected BE strains. In combination with organic recycling fertilizers, significant and reproducible effects have been recorded mainly for microbial BE combinations with manure-based fertilizers but not with composts or sewage sludge (Thonar et al., 2017). Particularly intense expression of BE effects was recorded during 4-years field testing in commercial greenhouse tomato production trials in Romania with 30% reduced fertilizer supply and in organic field production of tomato in Hungary with average yield increases by 52% and average economic benefits of € 28.600 ha^{-1}.

The right set of circumstances

Taken together the results demonstrate that the efficiency of bio-effectors is largely determined by the application conditions, leading to the concept of „*The right Set of Circumstances*" Under these conditions significant und reproducible effects can be expected and even BEs of different origin frequently showed similar effects Our challenge is a clearer definition of these conditions, and to identify management tools to meet these requirements for improved integration into agricultural practice. With the current state of knowledge the use of microbial BEs as biofertilizers was most promising in horticultural applications, at least partially conducted under controlled conditions (e.g. greenhouse culture) largely excluding environmental stress factors during the establishment phase . In agricultural production systems, reproducible effects are frequently biased by hardly predictable

environmental impacts and a lack of adapted and economic application strategies. However, the use of non-microbial BEs as stress protectants revealed some promising perspectives also for agricultural production.

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