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Opinion

Commercialization of Plant Probiotics as a Tool toward Global Sustainable Intensification of Agriculture

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In the present times, long-lasting ecological equilibriums are challenged by human activities at a global scale. With world population expected to grow 25% in the next 20 years, it is likely that the environmental pressure that we exert would also increase. If we want to avoid the uncertainties derived from a climate changing scenario, matching economic growth to sustainability is arguably the most important challenge needs tackling. On the other hand, more and better food will be required in the coming years, putting farming practices in a hotspot for building up a sustainable future [1].

The agricultural sector, with few notable exceptions like the slash-and-burn method or the dairy/meat industry, does not contribute strongly to greenhouse gas emissions, due to the balancing effect of the carbon sequestered during plants' growth and fructification. Nonetheless, farming in its present, conventional form, is considered unsustainable, as it heavily depends on external inputs, mostly synthetic fertilizers [2]. Although industrial nitrogen forms are mostly responsible for the increased agricultural productivity over the last few decades, its pervasive use came with various negative environmental implications. Firstly, nitrogen fertilizers are produced starting with the Haber-Bosch process, an energy intensive chemical transformation that burns non-renewable gas resources to fix molecular nitrogen into ammonia. With an estimated annual production of 450 million tons of nitrogen fertilizers, this process alone is responsible for as much as 5% of the total use of extracted methane [3]. Furthermore, leaching of nitrogen fertilizers from the fields negatively impacts water bodies causing eutrophication, a phenomena that has many times led to massive death of fishes and other aquatic animals [4]. Nonetheless, in the authors' view, one of the worst aspects related with the effectiveness of fertilizers is a cultural one: it has allowed farmers to start viewing the plant as a simple mean of production, totally dissociated to the natural cycles that so heavily depends on. As a consequence, promoting farmers' adoption of sustainable practices, often based on a system view of the plant-soil interactions, will not be trivial.

Sustainable farming practices: the gap between knowledge and implementation

In the last two decades, we have experienced a rising institutional and societal awareness on the environmental problems associated with the linear economic process. This has led to the circular economy framework and to a general appreciation of more sustainable production models. The same has happened in the agricultural sector, where a better use of resources is being promoted by the combination of an ever-growing appetite for organic food, the introduction of new regulations, and an increasing funding availability for researching sustainable innovations. Particularly, the latter has contributed to generate a wealth of knowledge in support of an holistic view of the belowground and aboveground agro-systems. From conservation tillage [5] to wildflower strips [6], from mixed cropping [7] to cover crops [8], many sustainable farming practices have been shown to improve productivity and hence economic benefits for the farmer. However, these agronomic methods seldom leave the research context and it is very important that institutions pay attention to the why [9].

In general, farmers strongly avoid uncertainties and are unlikely to adopt technical innovations whose benefits have only been proved in very specific contexts. They tend to focus on crops and short term returns, showing closure towards practices that takes years to master and have mostly indirect effects on productivity. On the contrary, when they do embrace changes, these most likely come in the form of new products brought by advisors or sales representatives with their set of financial incentives. In this scenario, the strength of agro-chemical companies is often based on offering easy-to-use applications that generate highly visible results. Focusing on this strategic advantage is of great importance for the development of innovative solutions for sustainable farming.

Fortunately, the negative impacts of industrial agriculture are growingly recognized by the public opinion. This element, together with the introduction of new regulations that limit the use of agrochemicals, is helping farmers to see the benefits of managing agricultural intensification sustainably. The rise of marketable solutions in this area will likely facilitate this shift and should be seen as a great opportunity to meet some of the 2030 sustainable development goals.

The beneficial activity of plant probiotics

Unsustainable agronomic practices and the heavy use of chemicals can lead to a situation where productivity is totally dependent on external inputs. Stimulating soil life and internally regulated processes is fundamental to restore the natural capability of plants to transform solar energy into food. As functional characteristics of healthy soils mostly depend on the orchestrated activity of microbes, microbial community engineering is seen as a great tool to promote sustainable production systems [10,11].

A number of benefits are provided to plants by the soil microflora in natural conditions. These go from mineralizing organic matter in a form easily absorbed by the root, to making available otherwise unaccessible micro-elements, from fixing atmospheric nitrogen, to defending the plant from pathogens and pests [12,13]. Interestingly, the evolutionary advantages provided by microbial communities have justified the appearance of mechanisms by which the plant nurtures its own specific microflora, mostly based on the secretion of root exudates that microbes are able to feed upon [14]. At their own advantage, bacteria and fungi have developed ways of dictating carbon release from the plant, closing the loop of a win-win situation that sustainable agriculture should take advantage from [15]. A better understanding of these dynamics, often crop-specific, at the field level, can improve rhizosphere engineering strategies to maximize product yield.

A few notable successes exist in this agronomical field. Clearly, inoculation of legumes with symbiotic rhizobial species should take the headline of plant probiotics, as the importance of these bacteria in providing nitrogen to the plant has long been recognized and commercially exploited [16]. More recently, improved yields have been obtained applying free-living N-fixing bacteria for various cereal crops [17]. Also, phosphorus solubilizing microorganisms have been commercially developed and initial results show that amelioration of soil with these bacteria can reduce phosphate fertilizer requirements of up to 75% [18]. Similar beneficial effect have been detected with Fe- and Zn-mobilizing bacteria [19,20]. On the other hand, many microorganisms are known to produce phytohormones for root uptake, which give them the ability to directly interfere with plant's physiology [21]. Commercial exploitation of hormone-producing bacteria can boost plant growth and stress response, ultimately increasing yield [13]. This are just a few examples of exploitable biological mechanisms but they give a sense of the tremendous opportunities provided by plant probiotics. The effectiveness of an inoculant will be maximized by developing a framework that integrates plant, bacteria and soil specificities in an easy-to-apply roadmap to community engineering at the farm level.

Generally, two approaches are possible to control community composition of plant's probiotic bacteria: using agronomical practices to favor the growth of site-specific taxa or inoculating the plant/soil with known beneficial species. Although the first strategy can be considered as the ultimate goal in the quest of a farmer that sees him/herself as the keeper of the natural ability of agro-systems to generate a harvest, it is undeniable that the latter is more easily adopted and managed by today's landowners. The thesis behind this article is that complementing the appearance of plant probiotic products with policies to help farmers understand the importance of soil diversity and functionality will be key to bring sustainability at the field level.

An opportunity not to be missed

Ultimately, farmers are responsible for implementing sustainable practices into their personal agronomical strategy. In order for them to feel confident in adopting new processes and products, they must perceive that both short-term monetary returns and long-term ecological benefits are met. The success of organic agriculture in the last decade can partially be attributed to providing such a balance. However, the full potential of the "bio-revolution" is far from being expressed [22] and the following elements related with plant promoting bacteria can boost its pace.

Firstly, marketable formulations should possess qualities such as being easy-to-use, easy-to-understand and simple to evaluate in a cost-benefits analysis. Their spread in the agricultural sector will be promoted by sale agents that for their own benefit, acting both as financial and technical advisors, share with the farmer the focus on quick returns. The effectiveness of these new products will contribute to the understanding, in the farmer's view, that nutrient availability to plants does not depend solely on fertilizers inputs, but rather is a result of microbial governed processes that take place within the soil.

Secondly, institutional policies should lower entry barriers for products based on plant probiotics. Further regulations that limit the use of agrochemicals, and financial aids toward sustainable practices, will all play a role in facilitating farmers implication. In this context, the increased awareness of general public regarding climate issues acts as a powerful force in dictating the political agenda. Not forgetting that the farmer too is not immune to the public opinion.

Lastly, for plant probiotics to represent a revolutionary force in sustainable agriculture, appropriate marketing messages are required. If bacterial formulations will be conveyed by the industry as "just another additive", farmers may consider the product itself as the only responsible for any given result. On the contrary, if the use of beneficial microbes will be presented as part of an holistic strategy for nurturing the soil, not only it will likely have better results, but it will favor a deeper understanding of ecosystem dynamics by farmer, as he/she will be held responsible for applying general knowledge and products to site-specific conditions. High levels of accountability always translate into more responsible behaviors and should facilitate integration of sustainable practices. Tackling climate change is an unprecedented task for human society, and countermeasures will come only if policy-makers, companies and end users will all embrace a systemic view of the problem, starting from agriculture.

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