

Review

Potential roles of biological amendments for profitable grain production – A review

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ABSTRACT

There is increasing interest in use of ‘alternative’ soil amendments in agriculture, but the wide range of resources and products available differ greatly in their potential to overcome soil constraints and improve nutrient use efficiency. The three main types of biological amendments can be categorised as biostimulants, organic amendments and microbial inoculants. Many have potential to influence biological, chemical and physical conditions of soil, but most are not well researched or easily used in agriculture. The main exception is legume inoculants, which are very well researched and contribute enormously to agricultural productivity when legumes are incorporated into farming systems. Biostimulants include amino acids, chitosan, seaweed extracts and humic substances. Organic amendments include manures, composts, compost derivatives and biochars. Microbial inoculants include specific bacterial inoculants for legumes, and less specialised rhizosphere bacteria, arbuscular mycorrhizal fungi, ectomycorrhizal fungi and a range of disease suppressing microorganisms. Some biological amendments applied to soil may be more effective when used in combinations rather than singly. Furthermore, those used over longer periods may have potential for cumulative effects not captured when used over shorter timeframes. Such differences in effectiveness would occur primarily where benefits involve microbial interactions with chemical and physical soil processes leading to slow transformations within the soil matrix that influence soil fertility and soil health. Similarly, addition of manures and composts may require several years for any quantifiable increase in soil organic C. Although considerable knowledge of the modes of action of many biological amendments is available, their performance under field conditions is usually less well understood. The wide variety of natural and manufactured products available in most cases precludes adequate peer-reviewed research to support claims about their effectiveness. This can lead to proliferation of unsubstantiated assertions of efficacy. This review highlights the lack of field-scale evidence of benefits for many biological amendments with potential to be used in agriculture. We propose complementary approaches of (i) laboratory- or glasshouse-scale research to understand modes of action, and (ii) targeted field-scale participatory research involving groups of farmers using on-farm trials as a forward pathway. Use of biological amendments to overcome soil constraints is expected to expand with intensification of agriculture and as a result of climate change. Therefore, information that enables farmers to discriminate among products that have different levels of effectiveness is necessary, and on-farm participatory research should contribute to addressing this need.

1. Introduction

A wide range of resources and products is available for use in agriculture as soil amendments to overcome constraints to nutrient use efficiency and productivity. Biological amendments applied to agricultural soils include biostimulants, organic amendments, microbial inocula, and pelletised formulations and extracts such as compost teas

(Quilty and Cattle, 2011; Traon et al., 2014; Yakhin et al., 2017). An important driver for continuing interest in use of biological amendments is the increasing focus on recycling of municipal wastes, industrial organic wastes, food processing wastes and sewage treatment wastes (Alvarenga et al., 2017). This encompasses reduced landfill and methane production and potential to return nutrient resources to agricultural land (Chen et al., 2016; Riggio et al., 2016). Although

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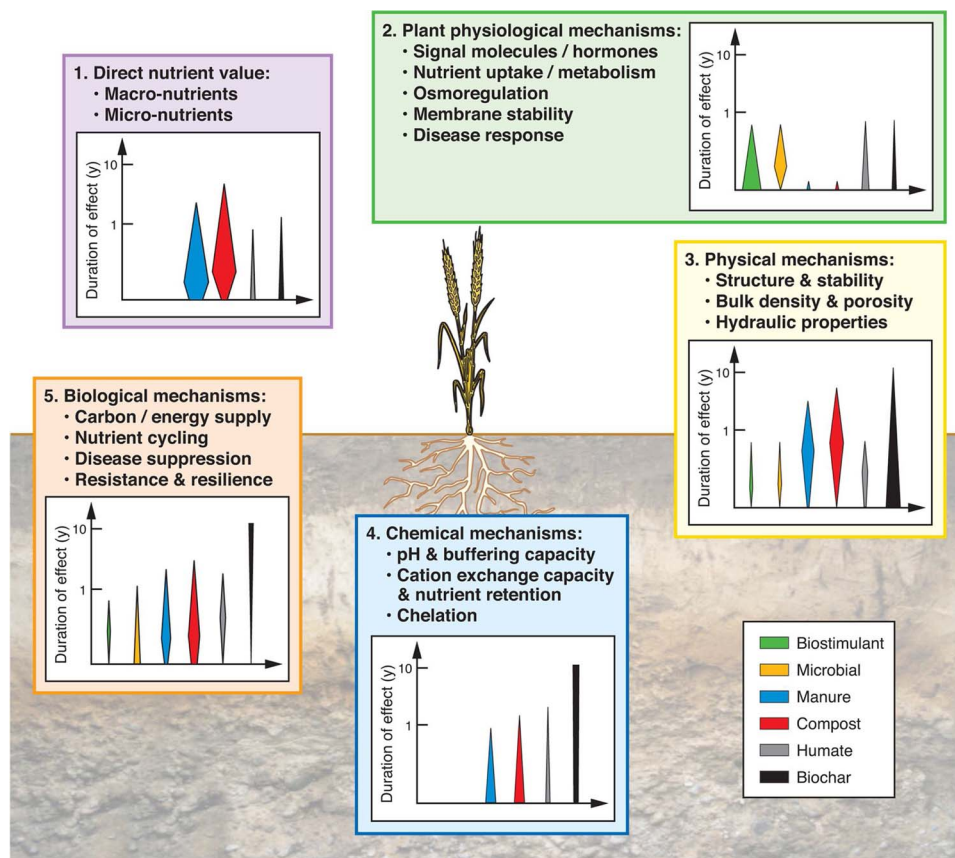


Fig. 1. Potential benefits from application of biological amendments in agriculture can be associated with direct nutrient contributions, plant physiological responses, and/or modifications in soil physical, chemical or biological components of soil health. The biological amendments are very varied but are categorised here as biostimulants (plant growth stimulants), microbial (including rhizobia for legumes and wider groups of microbial inoculants), manure and compost, humates (humic substances, some of which also fit the category of biostimulants), and biochar (includes biochars with a range of different properties). The width of bars indicates estimates of generalised intensity of response and the length of the bars indicates duration of response in years (y). Generalised effects include a range of methods of application and modes of action.

various forms of biological amendments have always been available, there are questions about their efficacy for increasing the profitability of agricultural systems (Quilty and Cattle, 2011), particularly when transport and application costs for the farmer are considered. Plant responses to biological amendments are often uncertain compared with conventional inputs used to ameliorate soil constraints to production.

As the range of biological amendments increases, it can be difficult to identify the appropriate amendments that will address local soil constraints with certainty and without introducing risks (Castán et al., 2016). Nevertheless, potential benefits from use of some biological amendments are related to direct nutrient contributions, plant physiological responses to stress, stimulation of plant growth not related to nutrition, protection against plant disease, and alterations in soil physical, chemical and biological components of soil health (Fig. 1). The magnitude and duration of any benefit will depend on the form and characteristics of the amendment, as well as the context of its application, including prevailing soil and climatic conditions.

Common soil biological constraints in agriculture include those related to low organic matter content (Hoyle et al., 2014; Aye et al., 2016). Soil C in cropped agricultural soils usually declines over time (Luo et al., 2010) unless there are significant changes in management practices, such as the inclusion of effective rotations. Soil organic matter may be augmented by application of compost or manures, with management practices that protect organic matter a high priority, but generally this is not currently a common option in rain-fed cropping.

Some biological amendments, including biostimulants, may offer the potential of improving the capacity of crops to tolerate a range of stresses. Seasonal constraints associated with moisture stresses that contribute to yield loss in crops include frost and heat-stress (Smith et al., 2009), and the amount and distribution of rainfall can lead to drought-stress (Heng et al., 2007). For example, short dry spells can occur in any season, even more frequently than droughts, and significantly affect crop yield (Rockström et al., 2010). As low and erratic

rainfall and temperature extremes become more common due to climate change (IPCC, 2007), a key consideration in these environments is to lower production risk by stabilising yields.

The use of biostimulants in agriculture has been estimated to be growing at an annual rate of 12.5% (Calvo et al., 2014) with projections for considerable expansion (Yakhin et al., 2017). The resurgence in interest in use of biological soil amendments includes use of products and processes for which there is often little or no scientific research underpinning their effective use or modes of action (Edmeades, 2002; Yakhin et al., 2017). In contrast, successful inoculant industries are underpinned by extensive research and tight regulation based on well-defined industry standards (e.g. legume inoculation (Howieson and Dilworth, 2016)). Scientific knowledge that enables confirmation of claimed benefits is not often published in the peer-reviewed literature and is therefore not widely available for most marketed products. Where information is available, it may be developed through participatory on-farm research (Schut et al., 2016) or experimental field trials (Speirs et al., 2013).

Within the context of emerging expansion of use of biological amendments in agriculture, and limited levels of justified evidence for their potential benefits when used by farmers, we aim to provide an overarching view of the range of biological amendments available, with evidence of their potential to improve productivity in rain-fed agricultural systems. Our intention is to provide a framework which could be used to guide decisions around the choice of amendments based on their modes of action and how they influence underlying constraints to agricultural productivity.

2. Potential benefits from use of biological amendments

Assessment of the potential benefits of biological amendments offers a means to decide whether their use is an appropriate management option to meet farm production objectives. They may include: (i)

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