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Use of a Bioaugmented Organic Soil Amendment in Combination with Gypsum for *Withania somnifera* Growth on Sodic Soil

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ABSTRACT

Limited availability of organic matter is a problem to sustain crop growth on sodic soil. Organic soil amendments are a cost-effective source of nutrients to enhance crop growth. A field study was conducted to evaluate the effect of an organic soil amendment bioaugmented with plant growth-promoting fungi (SF_{OA}) in combination with gypsum on soil properties and growth and yield attributes of *Withania somnifera*, one of the most valuable crops of the traditional medicinal system in the world, on a sodic soil at the Aurawan Research Farm of CSIR-National Botanical Research Institute, Lucknow, India. The SF_{OA} used was prepared by pre-enriching farm waste vermicompost with plant growth-promoting fungi before mixing with pressmud and *Azadirachta indica* seed cake. The application of SF_{OA} at 10 Mg ha^{-1} after gypsum (25.0 Mg ha^{-1}) treatment significantly ($P < 0.05$) increased root length (by 96%) and biomass (by 125%) of *Withania* plants compared to the control without SF_{OA} and gypsum. Similarly, the highest withanolide contents were observed in leaves and roots of *Withania* plants under 10 Mg ha^{-1} SF_{OA} and gypsum. Combined application of SF_{OA} and gypsum also improved physical, chemical and enzymatic properties of the soil, with the soil bulk density decreasing by 25%, water-holding capacity increasing by 121%, total organic C increasing by 90%, pH decreasing by 17% and alkaline phosphatase, β-glucosidase, dehydrogenase and cellulase activities increasing by 54%, 128%, 81% and 96%, respectively, compared to those of the control. These showed that application of the SF_{OA} tested in this study might reclaim sodic soil and further support *Withania* cultivation and results were better when the SF_{OA} was applied after gypsum treatment.

Key Words: medicinal crop, plant growth-promoting fungi, soil property, soil reclamation, vermicompost

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INTRODUCTION

Soil sodicity is one of the major edaphic factors limiting crop production and environmental quality (Lakhdar *et al.*, 2010). In general, sodic soils are characterized by high pH (8.5–11.0), high exchangeable sodium percentage (ESP) (45%–85%), unfavourable soil physical properties and reduced availability of plant essential nutrients. These characteristics of the sodic soils have negative influences on plant growth and yield (Qadir *et al.*, 2001). Several studies have been developed to make sodic soils cultivable by using different chemical amendments, such as gypsum and sulphuric acid (Srivastava *et al.*, 2011a; Rasouli *et al.*, 2013). Gypsum is a moderately soluble source of the plant essential nutrients calcium (Ca) and sulphur (S), and crop growth may be improved in gypsum-treated soils (Choudhary *et al.*, 2004; Dick *et al.*, 2008). Use of gypsum may prevent soil dispersion by maintaining a high Ca:sodium (Na) ratio and thus promoting clay flocculation and structural stability of soil (Yaduvanshi and Sharma, 2008). However, gypsum is not able to restore the soil biological activities, which are the basis of sustainable soil fertility (Clark *et al.*, 2007). Alternatively, the incorporation of organic amendments may be a useful method of reducing the deleterious effects of soil sodicity because it induces the mobilization of native soil Ca^{2+} from calcium carbonate ($CaCO_3$) and other Ca-bearing minerals through organic acids and enhances microbial decomposition (Li and Keren, 2009; Choudhary *et al.*, 2011). As a consequence, the concentration of Ca^{2+} ions increases at the cation exchange sites, which prevents Na^+ from entering the exchange complex (Walker and Bernal, 2008). Furthermore, the application of organic amendments enhances the soil microbial biomass and enzymatic activities (Lakdhar

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et al., 2009). Incorporation of organic amendments into the subsoil layer helps in sodic soil reclamation by improving aggregation, porosity and biological activities. Use of plant growth-promoting microbial cultures together with organic amendments may be an effective technique to enhance crop growth. The inoculation of beneficial microbial cultures (cyanobacteria, fungi and bacteria) into sodic soils can improve soil quality and productivities of different crops such as wheat and sugarcane (Shukla *et al.*, 2008; Gill *et al.*, 2009; Yadav *et al.*, 2009; Choudhary *et al.*, 2011).

Withania somnifera (L.) Dunal (Solanaceae), popularly known as Ashwagandha, is one of the most valuable crops of the traditional medicinal system in the world, especially in Asia (Sangwan *et al.*, 2004). Most of the therapeutic properties of *W. somnifera* reside are associated with its characteristic constituent known as withanolide. Its leaves, stems and roots are the main sources of withanolide. The biological activities of withanolides, especially withanolide A and withaferin A, have been reported for their anticancerous properties (Mirjalili *et al.*, 2009). In India, *W. somnifera* is cultivated over an area of 10 780 ha with a production rate of 8 429 Mg per year. Ever increasing demand of *Withania*-based medicinal amendments and products are necessitating the increase of *W. somnifera* cultivation for higher production.

About 3.7 million ha are affected by sodicity in the Indo-Gangetic alluvial plains of northern India. These sodicity-affected areas after soil reclamation may provide additional cultivable areas for increasing the production of economically and medicinally important crops as *W. somnifera*. Germination is one of the most salt-sensitive plant growth stages and is severely inhibited with increasing salinity (Plaut *et al.*, 2013). In this context, studies revealing the impact of organic amendment application to support *Withania* cultivation in reclaimed sodic soils may be quite useful. Organic amendments that are relatively inexpensive and easily available may economically ameliorate the sodic soils. However, few studies were based on the impact of the combined organic amendments on sodic soil reclamation and crop growth. The present study was undertaken to develop a bioaugmented organic amendment to optimize growth and yield of valuable crops on sodic soils.

MATERIALS AND METHODS

Study site

A field experiment was conducted during two cropping seasons (2010–2011 and 2011–2012) at the Aurawan Research Farm (80°53′ E and 26°45′ N, 129 m above sea level) of CSIR-National Botanical Research Institute (CSIR-NBRI), Lucknow, India. The climate of the farm is semi-arid subtropical with dry, hot summers and cold winters. The mean monthly minimum and maximum temperatures were 19 and 39 °C during the summer (April–June) and 4.7 and 32 °C in winter (November—February), respectively. The average annual rainfall was 1 045 mm, and cumulative open pan evaporation was 1 750 mm. According to IUSS Working Group WRB (2006), the soil was a solonetz, with a dense, strongly structured clayey subsurface horizon that has a higher proportion of adsorbed Na ions. The soil was strongly alkaline (pH 9.5) in nature, with total organic carbon (C), available nitrogen (N), phosphorus (P), potassium (K) and $CaCO_3$ equivalent of 3.4 g kg^{-1}, 0.2 g kg^{-1}, 47 mg kg^{-1}, 152 mg kg^{-1} and 9.6%, respectively. The soil had a high ESP of 60%.

Preparation of the bioaugmented organic amendment

The bioaugmented organic amendment (SF_{OA}) was prepared by mixing pre-enriched vermicompost (5.0 Mg) with pressmud (5.0 Mg) and *Azadirachta indica* seed cake (1.0 Mg) according to Srivastava *et al.* (2014). Vermicompost was prepared in a field-established vermicomposting centre at the Research Farm of CSIR-NBRI according to the method of Srivastava *et al.* (2011b) by using farm waste of mixed leaf litters of *Acacia nilotica* Delile sub sp. *indica* (Benth.) Brenan; *Eucalyptus tereticornis* Sm.; *Albizia lebbeck* (L.) Benth.; *Azadirachta indica* A. Juss.; *Leucaena leucocephala* (Lam.) de Wit.; *Terminalia arjuna* Wight and Arn.; *Prosopis juliflora* (Swartz) DC.; *Dahlia pinnata* Cav.; *Polianthes tuberosa* L.; *Bougainvillea glabra* Choisy; *Plumeria rubra*; *Cassia fistula* L., *etc.* The vermicompost was inoculated with 2% (volume/weight) of plant growth-promoting fungus (PGPF) strains (as a suspension of 10^8 colony-forming units (cfu) mL^{-1}) and then incubated for 7 d before mixing with pressmud and *A. indica* seed cake for soil application (Srivastava *et al.*, 2012, 2014). The PGPF inocula were prepared from four individual fungal strains, *Trichoderma longibrachiatum*, *Westerdykella aurantiaca*, *Lasiodiplodia* sp. and *Rhizopus delemar*. The fungal strains were mass-cultured in mycological broth (Hi-Media, Mumbai, India) before inoculation. The basic physicochemical characteristics of the vermicompost, pressmud, *A. indica* seed cake and the SF_{OA} determined using the same methods for soil samples as described below are given in Table I. The pressmud used in the study was procured from the M/s Bajaj Private Limited, Kheri, India and *A. indica* seed cake from a local market. Pressmud is a useful organic waste by-product of the sugar industry holding a great source of nutri-