Nano-Nutrients for Carbon Sequestration: A Short Communication

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Abstract

Global food production mainly depends upon the productive outcomes of the agricultural sector. Soils are the pool of nutrients required for plant growth. These nutrients directly enhance the crop yields and immune against the multiple biotic and abiotic stresses. These nutrient elements also supplement human food with these elements. It is a well-established fact that balanced nutrition results in the healthy growth of plants which can combat different stresses. Conservation agriculture is the key sustainable measure for increasing food security, alleviating poverty, biodiversity conservation, and safeguarding ecosystem services. Nano-fertilizers are also eco-friendly sources by maintaining a balance of C sequestration and N emissions in the environment. Nano-fertilizers, because of their unique properties, are now a promising approach to enhance soil, fertility, enhance plant growth, and improve soil C sequestration.

Keywords: Climate change; Nano-management; Conservation agriculture; Smart agriculture; Carbon sequestration

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1. Soil carbon sequestration and its potential

Carbon is the main element for producing the organic matter beside hydrogen and oxygen, which is the basic unit for any living organisms. Cultivated plants can catch carbon from atmospheric air through the photosynthesis process in the form of CO₂. This gas also can be produced by the respiration of living things and the decomposition of plants residues as...
well as the soil fauna and microbes. Soil organic carbon or soil organic matter (SOM), which resulted from any source of organic materials, is the main key component in soil controlling several properties of soil (i.e., physical, chemical, and biological properties). Several benefits of SOM have been reported long yearsago including soil quality improving, which leads to increase the crop productivity due to increased retention of water and nutrients (Ontl and Schulte 2012). The role of SOM is very clear under different climatic zones as presented in Fig. 1 (for the temperate climate in Germany) and Fig. 2 (for the arid climate in Egypt).

Due to continued increase in CO₂ and other greenhouse gases (GHGs) like N₂O, and CH₄, which result from human activities, the earth’s climate is rapidly changing (Raza et al. 2021). Atmospheric CO₂ concentrations have risen from nearly 280 parts per million (ppm) prior to 1850, to 410.5 ppm in 2019, to 413.2 ppm in 2020 (WMO 2021). Therefore, soil C-sequestration is a process in which CO₂ is removed from the atmosphere and stored in the soil carbon pool (Ontl and Schulte 2012, Elbasiouny and Elbehiry, 2020a).

As reported by many researchers, organic C-sequestration in soil could be enhanced by the chemical, physicochemical and biological protection to SOC through recalcitrance of SOC, facilitating the organo-mineral interaction, and protecting SOC from microbes andmicrobial decomposition, respectively(Barré et al. 2014; Pramanik et al. 2020). The main recommended management practices for enhancing the C-sequestration include conservation agriculture (Lal 2015; Jayaraman and Dalal 2021; Ranjan et al. 2021), conservation tillage (Jayaraman et al. 2021), agroforestry (Hübner et al. 2021), adoption of diversified cropping systems (Ngangom et al. 2020), integrated nutrient management (Ghimire et al. 2017; Gogoi et al. 2021a, b), mulching (Ngangom et al. 2020), improved grazing (Sarkar et al. 2020; Mattila et al. 2022), and forest management (Pramanik et al. 2020; Ameray et al. 2021). Many approaches for managing soil C-sequestration could be found in Table 1.

2. Nano-nutrients and climate changes

The cultivated plants need in their growth certain nutrients, which they should be available for plant uptake by their roots. These (Plant) nutrients are essential for increased crop productivity and food supply to sufficient levels (Daniyan et al. 2017). To gain the proper amount of these nutrients by cultivated plants, soil fertility and its quality should be sustained by improving soil physical and chemical characteristics (Li et al. 2017). For getting higher crop productivity, cultivated plants may need exogenous applying nutrients by mineral fertilization process, which it may cause environmental pollution (Abdulhameed et al. 2021). Nano-nutrients are considered a sustainable solution and alternatives can substitute these (traditional) mineral fertilizers, which have high use efficiency and eco-friendly source for nutrients (El-Ramady et al. 2021a). These nano-nutrients have also the ability to increase these nutrients bioavailability and bioactivity because of their greater surface area, more reactivity, better nutrient solubility, reducing fertilizer nutrient loss rate, reducing adsorption and fixation, and extending the duration of nutrient release in soil (Kalia and Kaur 2019). These (there are forms of) nano-nutrients could apply to cultivated plants in many formslike nano-enabled fertilizers, nano-based release nutrients, nano-chelated silicon fertilizers, nano-porous materials, nano-scale additive fertilizers, and nano-scale coating fertilizers (Guo et al. 2018; Basavegowda and Baek 2021).

Climate change is a global problem, which may include extreme weather events, rising in temperatures, flooding, changing in precipitation patterns, droughts, extreme heat stress, and sea level rise (Elbasiouny and Elbehiry, 2020b, El-Ramady et al. 2021b). Climate and its elemental factors (temperature, precipitation, pressure, wind, etc.) totally control the growth and production of crops beside the essential nutrients. It is found that the nutrient availability can impact on the physiological response to increased CO₂ and temperature (Liu et al. 2020). The usage of nano-nutrients in enriching cultivated crops has a promising progress like nano-Cu, nano-Fe, nano-Se, and others. Recently, several publications have been issued concerning the impacts of changing in climate on the nutrition of cultivated plants like Liu et al. (2020), Krüger et al. (2021), Kumar et al. (2022), but a few on the plant nano-nutrition like El-Ramady et al. (2018), Sharma et al. (2019), Mishra and Khare (2021), Mahapatra et al. (2022), which confirmed that there is a need for the technology of nano-agro-nutrients. (Reword) Climate
change can impact on (mainly affect) plant nutrition, which mainly will impact on food security through basically of elevated [CO2] and higher temperatures on cultivated plants (Leisner 2020), as well as the influence of climate change on plant-herbivore interactions (Kuczyk et al. 2021; Zytynska 2021). Climate change may lead to the nutritional imbalance in cultivated plants under rising atmospheric CO2 (Kundu et al. 2022), so there is a need for producing crops of (in) the future, which have a climate-resilient plant immune system (Kim et al. 2021).

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Fig. 1. Four different soil profiles from Göttingen in Germany were presented during the Annual Meeting of the German Society of Soil Science, which held during September 2017. The impact of soil organic matter including the plant roots could be distinguished in all soil profiles. All photos by El-Ramady.
3. Nano-nutrients for C-sequestration in agricultural soils

Modern innovations like nano-enhanced products (such as nano-fertilizers and nano-pesticides) with a nano-based smart delivery method providing nutrients at the target sites, time, and rate to improve productivity can be used to use state-of-the-art in understanding the processes leading to SOC sequestration (Jinus et al., 2021). Nanotechnology has a great potential for improving terrestrial C pools for better soil health and a cleaner environment. Because of their distinct characteristics, nanomaterials (NMs) have been shown to improve C stabilization and its possible soil sequestration. Soil C is influenced by a wide range of edaphic, environmental, and management factors, the most important of which are soil aggregation and structure (Pramanik et al., 2020). Mani and Mondal (2026) reported that the nanoparticles (NPs) have a proclivity to aggregate and interact with organic colloids (such as dissolved organic matter (DOM), humic materials, polysaccharides, and peptidoglycan), and it is thought that NPs, due to their high surface-to-volume ratios, might be extremely successful in C-sequestration. The NPs are the most significant adsorbents in soil, and they can regulate nutrients transport, control OM fixation, and stimulate the new mineral phase's precipitation. (Reword) The NPs in soil are of critical importance in the future.

In addition, NPs have direct impacts on plants, such as enhanced the activity of plant enzyme, improved seed germination, higher plant tolerance to negative circumstances, enhanced C sequestration and N fixation, and enhanced photosynthetic and respiratory activities. As a result, the plant biomass and nutritional condition are greatly improved, resulting in higher crop returns (Kalia and Kaur et al., 2019). In this context, biochar is known that it can retain C for a longer time compared to organic waste due to its higher stable structure, and long-term stability, thus, GHGs emission is decreased during manufacturing and after soil application.
Biochar application is a C sequestration approach (Elbasiouny et al., 2021). Recently, nano-biochar is also a promising approach in this context, it is a more enhanced biochar where it can absorb nutrients and enhance soil fertility, thus C sequestration and green and sustainable agriculture (Khan et al., 2021).

Conflicts of interest
This article does not contain any studies with human participants or animals performed by any of the authors.

Consent for publication
All authors declare their consent for publication.

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Conflicts of Interest
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