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Can Nano-Fertilizer be a Solution Against Global Water Crisis? An Overview

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Abstract

Water is an indispensable element for all living organisms for sustaining human existence, food security, societal advancement, and biodiversity. Due to global climate change, an increase in the shortage of fresh water supply is noticed leading to global water crisis. Traditional and non-traditional approaches as solutions against global water crisis were reported. Applied nanotechnology might support and provide promising strategies to overcome many global issues like global water crisis. The suggested applied nano-solutions may include nanofertilizers, and nano-sensors, and nano-management of wastewater. Nanofertilizers have distinguished features against global water crisis, which can increase the water use efficiency by cultivated crops, especially under stressful conditions. Many reports confirmed that applied nano-fertilizers can directly and/or indirectly save water along with an effective role of such fertilizers under water stress. This role of nanofertilizers may back to its features that enhance productivity of cultivated plants under water stress through physiological, biochemical, and anatomical issues. This study opens many windows towards the expected issues of nanofertilizers against water crisis including direct and indirect attributes. Further studies in this important global issue are needed especially under the global challenges with a great concern on global climate change.

Keywords: Climate change, Food security, Global warming, Nano-agriculture, Nanotoxicity, Water security

1. Introduction

No doubt that water is an essential and vital for human life. It is noticed that only 3% of water resources on the Earth is freshwater and 70% of the Earth's surface is covering by water [1]. Over 2 billion people live under water scarcity, whereas a double of this number at least one month per year live under such scarcity [2]. The main areas that suffer from water stress may include arid and semi-arid regions, whereas temperate and tropical regions are vulnerable to limited water security under climate change [3]. It could be addressed water scarcity by two approaches including improving the practices of water use efficiency and replacing traditional sources of potable water by different water streams [2]. Global water crisis refers to the water shortage and is identified as the third highest risk of global concerns according to The World Economic Forum [4]. Thus, a significant threat to human development can be expected under the global water crisis due to increasing the scarcity of freshwater [1]. Several reports on global water crisis were issued from different regions such as Africa [5], Pakistan [1], China [6], Egypt [7], Iraq [8], Iran [9], India [10], and Ghana [11].

The sector of agriculture is a very dynamic industry that rapidly can accept daily enormous changes, updates, and expand to meet the basic human demands. Mineral or chemical fertilizers have a fast response by cultivated crops, but along with excess applied of such fertilizers may leachate reaching to the ground water, ponds or lakes, causing damage to the aquatic ecosystems [12]. Therefore, alternative fertilizers are needed to replace, even partially, mineral fertilizers by applying organic fertilizers [13], biofertilizers [14] and nanofertilizers [15]. Based on the type of nutrients, there are several nanofertilizers including many elements such as iron [15], carbon [16], and zinc [17]. Nanofertilizers have promising features as eco-friendly source and slow-release nutrients such as minimizing nutrient leaching, enhancing plant nutrition under stress, improving the nutrient use efficiency, promoting sustainable agriculture [18-23].

Therefore, this mini-review highlights the role of nanofertilizers in increasing the use efficiency of nutrients and water. Global water crisis and promising features of nano-fertilizers will be discussed in this study. Can nano-fertilizers help in saving water through direct and/or indirect approaches?

2. Global water crisis

Approximately 3/4 of our planet's surface is covered by water, with a total around 1385.5 BCM (million cubic kilometers). The majority of such water is saltwater (97.3%), whereas only 2.7% is freshwater. These freshwater resources include frozen water in glaciers and polar ice caps (75.2%), while the rest of unfrozen freshwater represents groundwater (22.6%), atmospheric vapor and soil water (1.9%), and in aquatic bodies including lakes and rivers as 0.3% [24]. There is increasing demand for water along with increasing global population. On the global level, the availability of freshwater resources faces many challenges due to several factors such as anthropogenic activities, population growth, groundwater overexploitation, industrial disposal, chemical farming intensification, and climate change [24]. Under global climate change, there is a significant change in global water supplies due to the magnitude and frequency of extreme events including flooding and drought, which is needed for effective water governance [25]. It is well known that human needs a steady supply of clean water to live, but this is not available to all global population due to the global water crisis (Fig. 1). Several reasons can cause the global water crisis including climate change, natural disasters, war and conflict, wastewater, forced migration and the refugee crisis, and inequality/imbalance of power.

Water scarcity could be defined as “a state of imbalance between the supply and demand of freshwater, where the demand for freshwater surpasses the available supply” [29]. Water scarcity can threaten the global sustainability of ecosystems [30], pose real limitations on the growth of economics and the social development [31]. It could be noticed also that many sustainable development goals (SDGs) are linked to the water scarcity including both direct and/or indirect approach [32]. Compared to the projected demand of water, it is expected to encounter a 40 % shortfall in its availability by 2030 [32]. Many researchers reported about the subjected solutions for the global water crisis, which can be listed in the following part:

(1) Rooftop rainwater harvesting to mitigate domestic, drinking, and irrigation water requirements with focus on water resources management, rainwater harvesting structures, wastewater reuse, and groundwater replenishment [24],

(2) Technology of solar stills as a reliable and sustainable solution for purification of water, and to provide accessible and clean water, especially under limited resources of energy and water scarcity [33],

(3) Incorporating different solutions to alleviate water scarcity through multiple solutions on water scarcity including (i) unconventional water, (ii) using of inter-basin water transfer, and (iii) improving surface water quality [34],

(4) Using the nexus of water, energy, food and are greenhouse gas emissions by considering the impacts of different management practices (mainly irrigation, and tillage) on the consumption of water and energy, as well as GHG emissions [35],

(5) Technology of atmospheric water harvesting through condensing the atmospheric water vapor by radioactive cooling surfaces along with morphology optimization and sorption technology [36],

(6) Freshwater harvesting using technology of solar-driven interfacial evaporation to produce clean water and wastewater treatment [37],

(7) Harvesting technology of atmospheric water using sorbent prepared from sugarcane bagasse wastes based activated carbon [38], and

(8) For the food-energy-water nexus, agri-voltaic systems (i.e., integration of agriculture with photovoltaic panels) can produce food, provide low carbon electricity, and conserve water on the same area of land [39].

3. Nano-fertilizers: promising features

It is well known that excessive application of chemical fertilizers causes several environmental problems including disruption of soil mineral equilibrium, reducing soil fertility, and irreparable damage of soil health [40]. Nanofertilizers (NFs) could be defined as modified or synthesized forms of bulk (traditional) fertilizer materials through physical, mechanical, chemical or biological methods. Many distinguished features of nanofertilizers can be realized as smart fertilizers, including higher surface area, small particle sizes, easy penetration, high solubility, controlled release, and abiding duration [18,41]. In brief, certain salient features of NFs can be addressed through increasing the plant growth under stressful conditions after foliar and/or soil application of NFs, acting as a defensible basis for plant nutrients, increasing fertilizer use efficiency and, reducing soil/water pollution [18]. NFs can be applied through soil and foliar application, along with seed nano-priming, and then uptake by plants by certain pathways (Fig. 2).

Based on different items, NFs can be classified into many categories based on their properties and composition, as reported by many researchers [22,40]. The selection of NF-type mainly depends on several factors related to soil conditions (pH, EC, OM, texture, etc.), cultivated crop (species, root exudates, etc.), nano-nutrient requirements (size, type, dose, etc.), and environmental issues (Fig. 3). Based on NF-composition, they can include nanostructured metal-based fertilizers, nanostructured polymer-based fertilizers, nano-biofertilizers, nano-coated/nano-encapsulated fertilizers, nano-composite fertilizers, nano-chelates, and bio-based nanofertilizers [42-44]. Based on NF-release mechanism, they may involve controlled-release nanofertilizers, slow-release nanofertilizers, and responsive nanofertilizers, whereas the following types can be addressed based on nutrient types; macronutrient-NFs, micronutrient-NFs, and complex nutrient NFs [20]. The common classification of nanofertilizers based on the synthesis method includes the physical, chemical, and biological approaches. Due to the ecotoxicological issue, the biological approach is preferable in agriculture and food sectors [19].

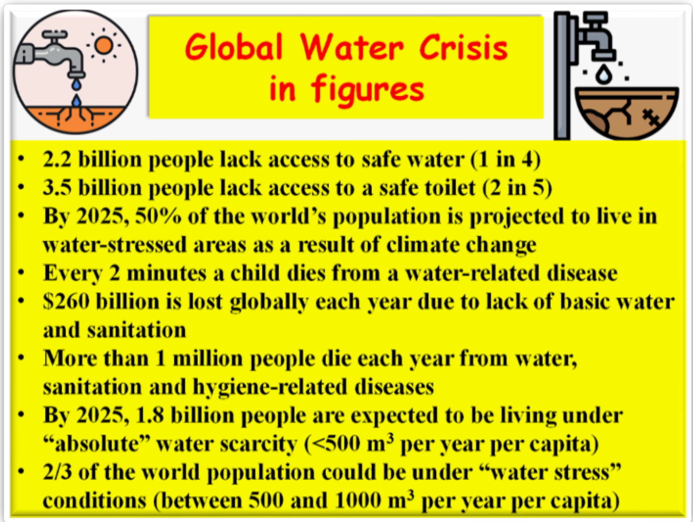

Fig. 1: Some facts on the global water crisis (Ref. [26-28], Sources: WHO 2020, 2023; FAO 2024; https://water.org/our-impact/water crisis/ accessed on 21.11.2024) source of images the following websites: https://www.flaticon.com/free-icon and https://www.veryicon.com/

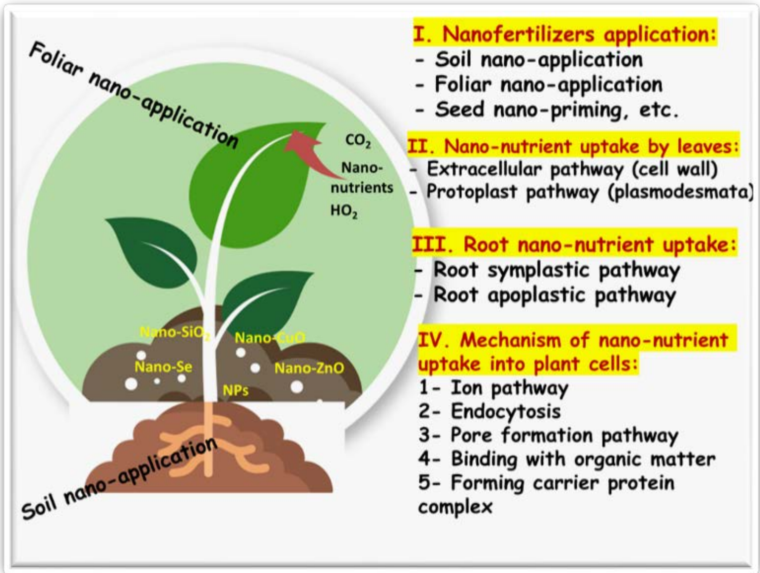

Fig. 2: Different methods of nanofertilizer application (part I, II, III) as well as the suggested mechanism of nano-nutrient uptake by plants (part IV) (adapted from Prokisch et al. [45])

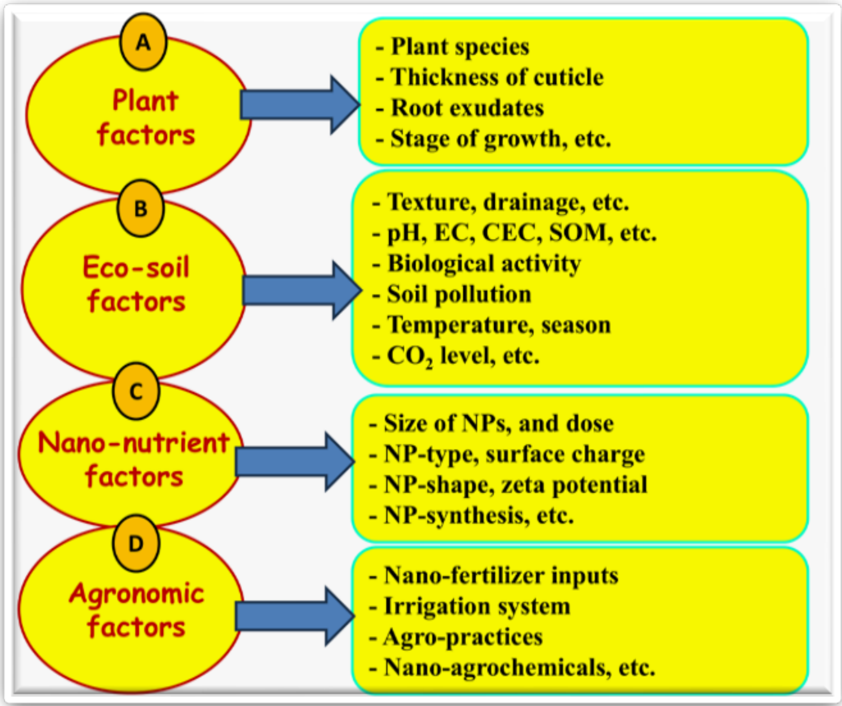

Fig. 3: Different factors control uptake of nano-nutrients in nanofertilizers by plants (adapted from Prokisch et al. [45])

Table 1. Selected studies on the role of nano-based fertilizers under water stress

Plant species	Applied dose	Stress details	Main impacts	Ref.
Pearl millet (*Pennisetum glaucum* (L.) R. Br.)	Zn-NPs (20 ppm) less than 90 nm	Stop irrigation from the 43 till 54 DAS	Ameliorated stress (electron transport and phenomenological fluxes)	[46]
Rice (*Oryza sativa* L.)	Nano-SiO_2 (400 ppm) 20–30 nm	Reduced irrigation water by 35%	Increased the yield and yield components	[47]
Quinoa (*Chenopodium quinoa* Willd.)	Nano-biochar 2% (40–100 nm)	60% from water requirements	Increased leaf chlorophyll and seed protein content	[48]
Maize (*Zea mays* L.)	O-Carboxymethyl chitosan- NPs (200 nm)	Air-dried seedlings in the oven for 80 min	Improved antioxidants, chlorophyll, and reduced peroxidation of lipids	[49]
Quinoa (*Chenopodium quinoa* Willd)	Chelated nano-Si fertilizer (2 g L^{-1})	Irrigation intervals from 14 to 28 days	Alleviated stress by promoting yield and physiological properties	[50]
Rice (*Oryza sativa* L.)	N-fertilizer nano-hydrogel at a 0.175 g N kg^{-1} soil	Flooding 50% SP, 30 mm submerged (extreme dryness)	Improved physio-biochemical attributes, thereby increased grain quality	[51]
Iranian sage (*Salvia mirzayanii* Rech. f. & Esfand)	CeO_2-NPs, 1000 ml L^{-1} (10-30 nm)	Up to 25% of field capacity (FC)	Supported re-watered and stressed growth plants and phytochemical attributes	[52]
Soybean (*Glycine max* L.)	Nano- Fe_2O_3; nano-priming 300 ppm, foliar rate 15 ppm	Irrigation at 50 % FC	Boosted yield and its quality by improving photosynthesis and chlorophyll fluorescence	[53]
Fava bean (*Vicia faba* L.)	nano-TiO_2 (15 ppm, 21 nm)	Withholding water supply foe 10 days	Induced osmotic/oxidative, antioxidant defense system	[54]

4. Nano-based fertilizers for saving water

Can nanofertilizers support plant growth and production under stress? On which base this ameliorative impact? What is the main mode of action? Can such nanofertilizers protect plants against water stress? To what extend can nanofertilizers protect plants again water stress? Many studies confirmed the role of NFs in enhancing plant tolerance against such stresses through many biochemical, physiological, and molecular mechanisms [23,44,46]. Along with this enhancement, there are some strategies for saving water by mitigation the water stress including direct and/or indirect methods (Table 1).

The following approaches were reported on the role of nanofertilizers or nanoparticles-based fertilizers in saving water:

1- Under water stress, applied nanofertilizers can induce plant physiological, morphological and molecular changes by improving content of pigments (i.e., antheraxanthin, chlorophyll, violaxanthin and zeaxanthin) and reducing non-photochemical quenching. This approach was reported on nano-Fe_2O_3 [53], nano-Zn [46], and carbon nano-dots [23],

2- Nanofertilizers can improve the yield and water use efficiency [55], and reduce consumed amount water leading to improve plant water productivity, protein of seeds and leaf chlorophyll content under water stress condition [48],

3- Using of nanomaterials in removing pollutants from water resources as an important source for saving water by increasing the adsorption capacity of applied nanomaterials for studied pollutants [56], through the magnetic nano-composite coagulant of pollutants in industrial wastewater [57], or treatment of algae -rich waters [58], or through the nano-bioremediation of soil and water [59],

4- Protecting the groundwater from pollution through applied nano-biochar, which reduced leaching of nutrients by enhancing water retention capacity of such pollutants [60],

5- Nano-sensors for water and humidity monitoring the human respiratory rates during various activities, e.g., coughing, running, standing and walking [61], or monitoring the water/wastewater pollution [62], and

6- In general, the concept of nano-farming, which means application of nanotechnology in different farming practices also, can support the saving of water in agriculture [63-65].

5. Nanosensors for saving water

It is well reported that nanotechnology has several applications in agriculture, which may impact directly and/or indirectly on managing and saving water through their nano-formulations such as nano-agrochemicals for crop improvement and nanosensors for the identification of such agrochemical residues and detecting plant diseases. Nanosensors are considered good tools for detecting nutrients/pollutants in water and soil, humidity or moisture, soil pH, pests, and pathogens to increase crop productivity [66]. Recently, many publications reported on the role of nanosensors in saving water through different approaches such as:

1- Promising monitoring approach of water quality and safety as real-world applications for in-field or online water monitoring [67],

2- Using a smartphone-assisted colorimetric detection strategy of organic pollutants (methyl orange) in environmental waters [68],

3- Trapping of inorganic pollutants (heavy metal ions of Ag, Au, Al, Mn, Sn, and Zn) by gallium nitride nano-cone for scavenging the water environments [69],

4- Application of smart irrigation management system for global food and water security [70], and

5- Using the smart nano-agrochemical including nanofertilizers and nano-pesticides for more nutrient and/or water use efficiency [71].

6. Conclusions and future prospects

Water is the main element for the life of human beings, which needs to protect, monitor, and conserve it. The applications of nanotechnology in water sector got a great concern due to many global issues such as global climate change and water crisis. Nanofertilizers are promising source in the agricultural production due to the distinguished features including the high surface area activity, high use efficiency, and slow release system. What is the role of nanofertilizers in water sector? Nanofertilizers can be a proper solution to overcome certain problems in such sector through saving water, purification, detecting the pollutants and nano-remediation of water/wastewater. For the sustainable approach, the biological nanofertilizers are needed with focus on more studies in the water sector especially under global climate change.

Author contributions: Both authors conceived of the presented idea, developed the theory and performed the computations, investigate and supervised the findings of this work. All authors discussed the results and contributed to the final manuscript.

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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