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Foliar nutrition of nano-fertilizers: A smart way to increase the growth and productivity of crops

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Abstract
The objective of this literature was to know the importance of effects of foliar nano-fertilization on different crops compared to conventional nutrient sources and methods of application. Nanoscience and Nanotechnology research in agriculture and horticulture are still at an elementary stage but developing rapidly. Conventional bulk fertilizer or traditional fertilizers are not only expensive for the producer, but may be harmful to humans and the environment. This has led to the search for environmentally friendly fertilizers or smart fertilizer, mainly those with high nutrient-use efficiency, and nanotechnology is rising as a promising alternative. More recently, foliar feeding has been widely used and accepted as an essential part of crop production, especially on horticultural crops. Although not as widespread on agronomic crops, the benefits of foliar feeding have been well documented and increasing efforts have been made to achieve consistent responses.

Keywords: Nanofertilizers, foliar nutrition, Agri and horticultural crops

Introduction
With the global upsurge in population and rapid urbanization, farmers across the globe are left with the daunting task of feeding more mouths every year it has prompted the large-scale use of fertilizers. As a result of resource constraints and low use efficiency of fertilizers, the cost to the farmer is increasing dramatically. Nanotechnology offers great potential to tailor fertilizer production with the desired chemical composition, higher nutrient use efficiency that may reduce environmental impact and boost the plant productivity. Nano-fertilizers are very effective for precise nutrient management in precision agriculture by matching with the crop growth stage for nutrient and by providing nutrient throughout the crop growth period.

Nanotechnology is an interdisciplinary promising research field, opening a vast number of opportunities in fields like medicine, pharmaceuticals, electronics, and agriculture. The term nanomaterials are generally used to describe the materials having a size between 1 and 100 nm. The small size and enormous surface area of such characteristics give unique properties for nanomaterials like optical, physical, and biological. Nano-fertilizers are new generation of the synthetic fertilizers which contain readily available nutrients in nano scale range. Nano fertilizers are preferred largely due to their efficiency and environment friendly nature compared to conventional chemical fertilizers.

Plant nutrition is crucial for agriculture production and crop quality, and 40% to 60% of the total world food production depends on the application of fertilizers. It is well known that, each of the nutrient element plays a major role in growth and development of the plants, and when present in deficient quantities can reduce growth and yields (Tisdale *et al*., 1993) [47]. Soil is the major natural source of plant nutrients. Soil may support growth and development of wild flora just sufficient for their survival and regeneration. However, intensive crop production that aims at high levels of productivity needs supplemental plant nutrition which may be given through soil application and/ or foliar application. Soil application of nutrients is the most common practice, but it has many limitations with respect to availability of nutrients to the plants. The inorganic nutrients get fixed in soil as insoluble forms and also subjected to leaching by rainfall or irrigation water (Alshaal and El-Ramady, 2017) [17]. Moreover, anything which restricts root growth reduces the nutrient uptake (Trobisch and Schilling, 1970) [48]. Foliar application overcomes these limitations. In addition to that, foliar feeding has proved to be the fastest way of correcting nutrient deficiencies and increasing yield and quality of crop products (Roemheld and El-Fouly, 1999) [37] and it also minimizes environmental pollution and improves nutrient utilization by reducing the amounts of fertilizers added to the soil (Abou-El-nour, 2002) [2]. The nano coated substances enhance the penetration via stomata with a size exclusion limit above 10 nm (Eichert *et al*., 2008; Pérez-de-Luque, 2017) [9, 33].

In addition to this, nanocarriers deliver the nutrients in the right place and right time which reduce the extra amount of active chemicals deposited into the plant system and increase the nutrient use efficiency.

Fig 1: Foliar application of nanofertilizers

Fig 2: Movement of nanoparticles within the plant system

Cereals

Morteza *et al*. (2013) [23] found that nano TiO_2 applied as a foliar spray in maize crop enhanced plant growth and grain yield by its efficient photocatalyst activity, which promoted the manufacturing of pigments and transformation of light energy to active electron and chemical activity. In maize crop with the foliar spraying of nano Zn nutrient increased the yield and yield components under water stress condition (Amin and Mohammad, 2015) [5].

Janmohammadi *et al*. (2016) [14] revealed that the delivery of Zn into barley seedling through spray of nano-fertilizer can be an efficient nutrient management strategy in semi-arid regions. Overall, our result indicated that the integration of nanotechnology in fertilizer products can improve fertilizer use efficiency and significantly increase of barley yield. This may be due to their stimulatory and catalytic effects on metabolic processes and their positive effects on yield and quality (Hansch and Mendel, 2009 [11]; Marschner, 2012 [20]). However, among the micronutrients, iron is essential for crop growth and food production. Iron is involved in the production of chlorophyll, photosynthesis, mitochondrial respiration, hormone biosynthesis (ethylene, gibberellic acid, jasmonic acid), production and scavenging of reactive oxygen species and osmoprotection (Hansch and Mendel, 2009) [11]. Moreover, zinc is a necessary component of various enzyme systems for energy production, protein synthesis, energy production, maintains the structural integrity of bio membranes and growth regulation (Hansch and Mendel, 2009) [11].

Janmohammadi *et al.* (2016) [22] reported that foliar application of $nTiO_2$ manipulates growth of barely, resulting in beneficial changes in yield and yield components. These possible reason for such a beneficial role is due to increase in activity of photosynthesis by promoting cyclic and linear phosphorylation by spraying of nano TiO_2 and it enhanced the photoassimilates supply in leaves (*i.e.*, increasing source capacity) which ultimately increased the yield attributes. (Gao *et al.*, 2013) [6]

Nano-scale zinc oxide particle at 40 ppm treatment was associated with increased rice grain yield and its components in mid tillering and panicle initiation stages (Ghasemi *et al.*, 2017) [7]. Foliar applications of nano-fertilizer had reflected in improvement in yield parameters of wheat plants (Abdel-Aziz *et al.*, 2018) [1].

Kumara *et al.* (2019) [9] found that the application of nano calcite foliar fertilizer has positive effects on growth, yield, seed quality and insect resistivity. 100 ppm nano calcite treatment with recommended soil added fertilizer could increase the final yield approximately about 1 ton ha^{-1}. However, higher concentrations of nano calcite greatly reduce the pest damages to the crop.

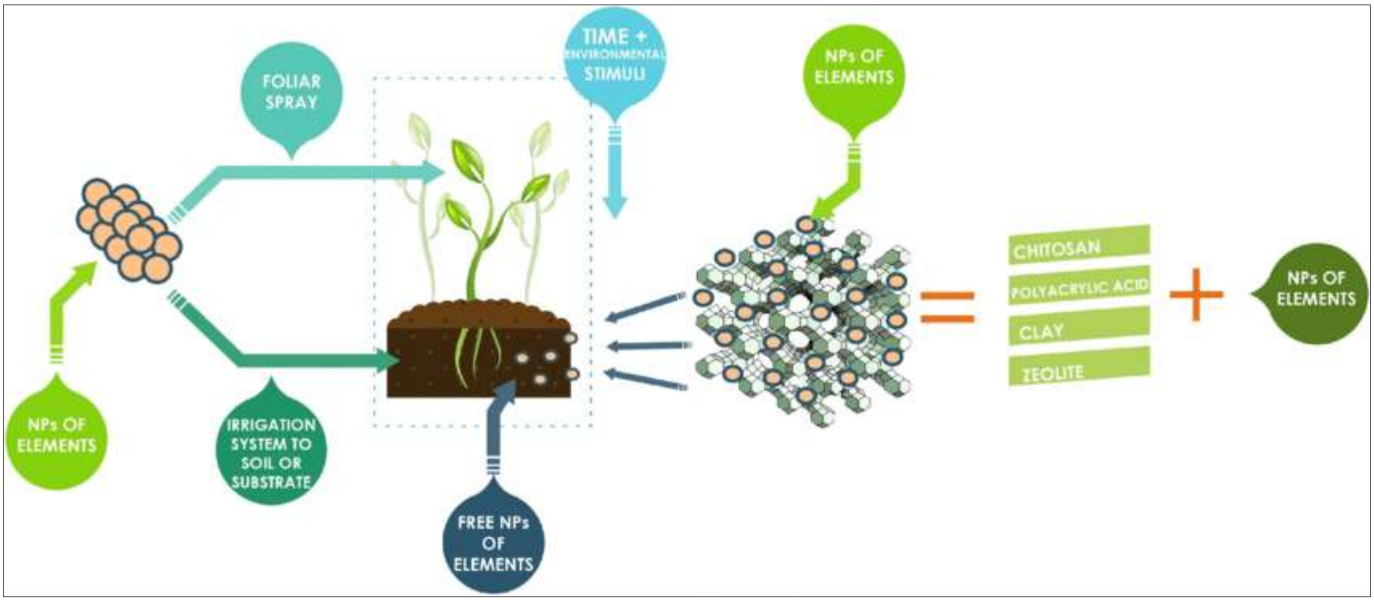

Fig 3: Method of application of nano-fertlizers

Millets

Tarafdar *et al*. (2014) [35] observed that Foliar application of zinc nano-fertilizer on pearl millet (Pennisetum americanum L.) significantly increased shoot length, root length, root area and plant dry biomass.

Marek *et al*. (2019) [18] reported that plant height, thousand grain weight, and grain yield quantitative parameters of foxtail millet did not differ statistically between ZnO NP-treated and untreated plants, the ZnO NP-treated plant grains had significantly higher oil and total nitrogen contents and significantly lower crop water stress index (CWSI). This highlights that the slow-releasing nano-fertilizer improves plant physiological properties and various grain nutritional parameters, and its application is therefore especially beneficial for progressive nanomaterial-based industries. In addition, there is interesting research showing that the photocatalytic effect occurring during early interaction of ZnO NPs with the leaf surface slightly accelerates the photosynthesis rate.

Pulses

Delfani *et al.* (2014) [7] suggested that spraying of 0.5 g L^{-1} nano Fe to the black-eyed pea improved the number of pods per plant, weight of 1000 seeds, yield, and chlorophyll content compared to common Fe. Foliar spraying of nanoformulations of NPK and micronutrients mixture increased the plant height and number of branches in black gram as indicated by Marimuthu and Surendran (2015) [19].

Mahnaz *et al*., 2015 [17], observed that foliar application of nano-iron chelate fertilizer, increased seed number per pod, pod number per plant, 100 seed weight and grain yield compared to control treatment 17, 48, 13 and 65% respectively. Seed priming with Zn, Fe and Ca nanoparticles improved 100 seed weight and grain yield compared to untreated treatment. Improvement in yield components as a result of application of nano-micronutrients might be due to the enhanced photosynthetic and other metabolic activity which leads to an increase in various plant metabolites responsible for cell division and elongation as opined by Hatwar et al. (2003) [12]. Iron has a great role in increasing growth characters, being a component of ferrodoxin, an electron transport protein and is associated with chloroplast. It helps in photosynthesis might have helped in better growth. (Hazra *et al*., 1987) [13].

Gomaa *et al*., (2016) [8] reported that foliar application of commercial nano- fertilizer (potacrystal and phosphoone) at two or three stages (vegetative, flowering or filling) increased yield and yield components of faba bean in both seasons.

Neama *et al*. (2019) [25] advised that foliar application of zinc nano-fertilizer increased the vegetative growth, fresh pod yield, pod physical quality (length, diameter, and fresh weight), dry weight, and pod nutritional value content expressed as P, K, Zn, Mn, Fe, Cu, crude protein, total soluble solids, and fiber of snap bean it may be due to the role of nano micronutrient stimulatory effects on the production of chlorophyll, photosynthesis, mitochondrial respiration, and hormone biosynthesis, e.g. ethylene, gibberellic acid, and jasmonic acid (Hänsch and Mendel 2009) [11].

Oil seeds

Foliar application of nano ZnS 500 ppm at 55 days after sowing significantly increased the seed yield of sunflower. Nano ZnO has proved to be more effective in enhancing productivity and absorption of Zn because of high surface area to volume ratio (Khanm *et al.*, 2018) [14].

Sheykhbaglou *et al*. (2010) [32] found that the use of iron nano-fertilizer on soybean crop improved the yield. Iron is a component of ferrodoxin and it may improve photosynthesis; iron deficiency might be a restricting factor for vegetative growth (Hazra *et al.*, 1987) [13].

Commercial crops

Foliar application of zinc nano-fertilizer on cotton crop increased fresh weight and dry weight have been recorded due to improved physiological processes like chlorophyll content and antioxidant activity (Rezaei and Abbasi, 2014) [27].

Drostkar *et al*. (2016) [8] reported that foliar spray of NPK nano-fertilizers in chickpea increased the yield and yield components as a result of increased growth hormone activity and enhancement of metabolic process, tended to increase in flowering and grain formation. foliar spraying of nano iron oxide recorded significant increase in boll weight and seed cotton yield compared to magnetite nanoparticles, normal iron oxide and iron sulphate fertilizers (Anon., 2015) [4].

Sohair *et al.* (2018) [34] reported that significant increases of total and open bolls per plant, boll weight and seed cotton yield with the foliar nano-fertilizers application than soil application. Application of nano-fertilizers have greater role in enhancing cotton yield production besides reducing the cost of fertilizer and also minimizing the pollution hazard.

Nabil *et al*. (2020) [24] observed that nanoparticles (NPs) treatments reduced the adverse effects of chilling by maintaining the maximum photochemical efficiency of (photosystem) PSII, maximum photo-oxidizable PSI (Pm), and photosynthetic gas exchange. Furthermore, application of NPs increased the content of light harvesting pigments (chlorophylls and carotenoids) in NPs treated seedlings. Higher carotenoid accumulation in leaves of NPs treated seedlings enhanced the non photochemical quenching (NPQ) of PSII. Among the NPs, nSiO2 showed higher amelioration effects and it can be used alone or in combination with other NPs to mitigate chilling stress in sugarcane.

Vegetable crops

Siddique, (2014) [38] found that application of SiO_2 nano-fertilizer can have a positive effect on plant growth and yield of cucumber under salinity condition through improved uptake of nitrogen and phosphorous and reducing the Na content. The SiO2 nanoparticle as foliar application avoided leaching loss of N and helped in more accumulation of nitrogen in leaf. Foliar applied SiO2 might help in increasing cell wall turgidity, strength and also cell wall elasticity during growth extension (Yassen *et al*, 2017) [37].

Juthery *et al*. (2018) [10] conducted a research study on potato and they opined that nano fertilizer (super micro plus), liquid seaweed fertilizer with hypertonic plant growth regulator applied treatment has given significantly higher followed by the di and single spray combinations, in yield of fresh, dry tubers, vegetative yield and biological yield giving 32.76, 7.280, 2.194 and 10.110 Mg ha^{-1}) respectively, compared with the control. This may be due to treatments applied can prevent plant from different biotic and abiotic stresses and consequently improve yield (quantity and quality) (Singh *et al*., 2017; Khan *et al*., 2017) [30, 15]. In consequence from above results we can concluded the importance of integral application of mineral, organic and growth regulator the very nice results with nan fertilizer applied in very low rate can open the door for more investigations in this field.

Ahmed *et al*. (2019) [3] opined that spraying of manganese oxide nanoparticles on the pumpkin plants led to the best vegetative growth characteristics, also, the characteristics of the fruits, yield, and the content of photosynthetic pigments.

On the contrary, the content of organic matter, protein, lipids, and energy gave the highest value in squash fruits that have been sprayed with iron oxide nanoparticles. This result might be attributed to the function of manganese in the process of photosynthesis, which turns the light of the sun into plant energy, which affects the formation of green plastids in the leaves and the production of chlorophyll.

Fruits

Vafa *et al*. (2015) [36] advised that growth parameters like plant height,leaf number and fresh and dry weight of savory plant get increased by nano-zinc application. It might be due to Zinc has an effect on synthesizing of natural auxin (IAA) and also can activate many enzymes involved in the biochemical pathways such as carbohydrate metabolism and protein.

Ali *et al*., 2016 [3], reported that a single foliar spray with relatively low amounts of B or Zn nano-fertilizers (34 mg B tree^{-1}or 636 mg Zn tree^{-1}, respectively) led to increases in pomegranate fruit yield, and this was mainly due to increases in the number of fruits per tree. The effect was not as large with Zn as with B. Fertilization with the highest of the two doses led to significant improvements in fruit quality, including 4.4–7.6% increases in TSS, 9.5–29.1% decreases in TA, 20.6–46.1% increases in maturity index and 0.28–0.62 pH unit increases in juice pH, whereas physical fruit characteristics were unaffected.

Sohreb *et al*. (2017) [43] advised that foliar application of nano N fertilization increased fruit yield (by 17% to 44%) and number of fruits per tree (by 15% to 38%). The highest fruit yields (17.8 and 21.9 kg tree^{-1}) and number of fruits per tree (62.8 and 70.1 tree^{-1}) were obtained with the treatment nN_2 (1.8 kg N ha^{-1}), whereas the lowest fruit yields (12.4 and 16.2 kg tree^{-1}) and number of fruits per tree (45.5 and 55.3 tree^{-1}) were recorded in the control trees. Pomegranate fruit yield was improved similarly with two applications (at full bloom and one month later) of nN_2 fertilizer at a rate of 1.8 kg N/ha and with two applications of urea at a rate of 16.3 kg N/ha. It may be due to processing of N uptake by plant roots can be limited by soil low temperature and low activity of roots, whereas foliar N application is insensitive to those factors (Etehadnejad and Aboutalebi, 2014) [5]. The increases found in fruit set, number of fruits per tree and crop yield with foliar N fertilization can be attributed to the physiological and metabolic roles of N in flowering and fruit set, including supplying carbohydrates, which are necessary for flower bud growth, flower initiation and development, ovule lifespan, effective pollination, and fertility (Etehadnejad and Aboutalebi, 2014; Lovatt, 1994; Stiles, 1999) [5, 16, 45].

Rasha *et al*. (2019) [28] reported that spraying grape vines with 0.4 ppm as nano-zinc increased significantly leaf area, leaf fresh weight and leaf dry weight compared with control. While, 1.2 ppm nano-zinc increased significantly total carbohydrate, leaf concentration of Fe, No. of clusters, cluster weight and yield. Also results showed that 0.4, 0.8 and 1.2 ppm of nano zinc had a significant increase on yield compred to conventional fertlizers.

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