Foliar application of nanofertilizers in agricultural crops –A review

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J. Farm Sci., 32(3): (239-249),2019

REVIEW ARTICLE

Foliar application of nanofertilizers in agricultural crops – A review

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(Received: August, 2019 ; Accepted: September, 2019)

Abstract: Green revolution had led to the increased consumption of chemical fertilizers which resulted in the higher productivity on one hand, where as on the other hand it also caused environmental hazards. Nutrient use efficiency of conventional fertilizers is very low. To overcome all these drawbacks in a better way, nanotechnology can be a ray of hope. Nano fertilizer is an important tool in agriculture to improve crop growth, yield and quality parameters with increased nutrient use efficiency, reduction in wastage of fertilizers and cost of cultivation. Nanofertilizers are applied either to soil and/ or leaves. Foliar application can be done during unfavourable soil and weather conditions. In addition to this, it promotes the direct entry of nutrients into the plant system, thus reduce the wastage of fertilizer. Hence, foliar application of nanofertilizer leads to higher nutrient use efficiency (NUE) and has given a rapid response to the growth of crops. Nanofertilizers are more reactive and can penetrate through cuticle, ensuring controlled release and targeted delivery. Present review summarizes the mode of action of nanofertilizers in to the plant system and effect of foliar applied nanofertilizers on crop growth, yield, quality, NUE and alleviation of abiotic stress and heavy metals toxicity.

Key words: Abiotic stress, Foliar spray, Nanofertilizer, Nutrient use efficiency, Phloem tissues

Introduction

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). 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). Moreover, anything which restricts root growth reduces the nutrient uptake (Trobisch and Schilling, 1970). 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) and it also minimizes environmental pollution and improves nutrient utilization by reducing the amounts of fertilizers added to the soil (Abou-El-nour, 2002). Even though leaves allow gas exchange, but cuticle present in the leaves restricts the penetration of substances (Schwab *et al.,* 2015; Pérez-de-Luque, 2017). 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). 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. Nano-fertilizers have high surface area, sorption capacity, and controlled-release kinetics to targeted sites, and have been considered as smart delivery system (Rameshaiah *et al.*, 2015; Solanki *et al.*, 2015). Indeed, it is necessary to study about the penetration and translocation of nanofertilizer through foliage and its effect on crops with respect of growth and development, yield, quality, tolerance to abiotic stress and alleviation of heavy metal toxicity.

Penetration and Translocation of nanofertilizer

Foliar applied fertilizers are facing several structural barriers, because the nutrients are salt based (cations/anions) which may struggle to penetrate the inner plant tissue cells. This is because of pore size of cell wall that ranges between 5 to 20 nm (Fleischer *et al.,* 1999; Benzon *et al.,* 2015; Schwab *et al.*, 2015). Hence, nanoparticles aggregate with diameter less than the pore size of plant cell wall which can easily enter through the cell wall and reach up to the plasma membrane (Moore, 2006; Navarro *et al.,* 2008). According to the polar pre-model, for the penetration of the polar and ionic solutes to the cuticle the exclusion limit of pore radius for has been estimated as 2 to 2.4 nm, where as for the stomatal diffusion the pore radius always exceeded 20 nm (Eichert and Goldbach, 2008; Pérez-de-Luque, 2017). The application of nanofertilizer is promising and efficient translocation of nutrients to the desired parts of plant (Deepa *et al.,* 2015). Engineered nanoparticles can penetrate the stomatal pores with the size of less than 50 nm as observed by Eichert *et al.* (2008) in *Vicia faba* L. and the size exclusion limit of stomata in the watermelon is 27.3-46.7 nm (Wang *et al.,* 2013). The foliar applied nanoparticles get transported from the site of application to the heterotrophic cells, which carried via the phloem vessels likely through the plasmadesmata (40 nm in diameter) (Knoblauch and Oparka, 2012; Etxeberria *et al.,* 2016). The uptake of nanoparticles into plant cells via binding to carrier proteins through aquaporin, ion channels and endocytosis (Nair *et al.,* 2010; Rico *et al.,* 2011). Nanoparticles can also be

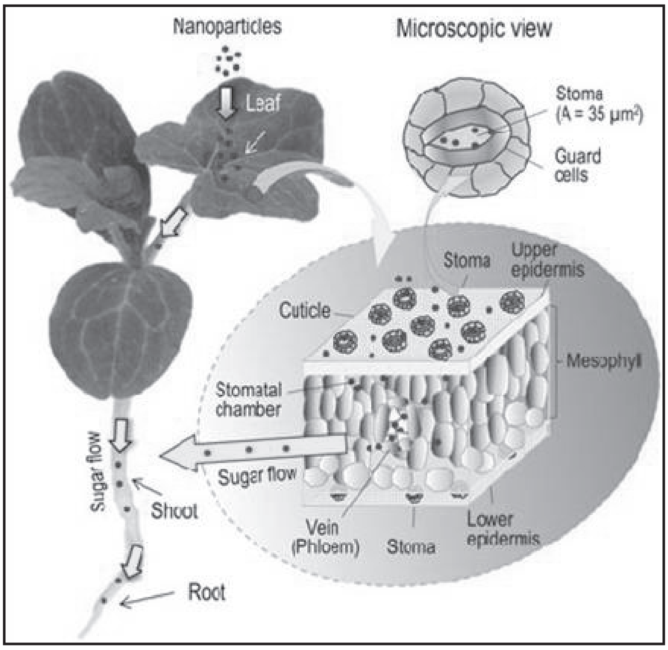

Fig.1. Mode of entry and translocation of foliar applied nanoparticles in to the watermelon plant (Wang *et al.,* 2013)

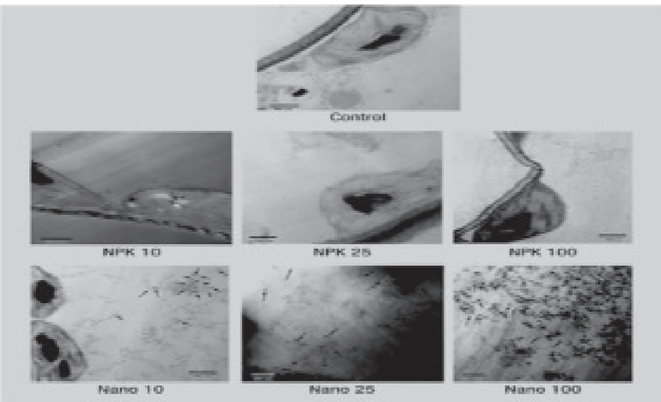

Fig. 2a. Presence of nanofertilizer in phloem tissues (Raliya *et al*., 2016)

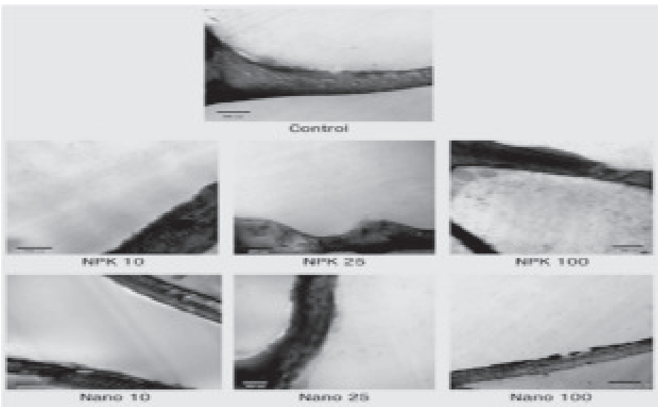

Fig. 2b. Absence of nanofertilizer in xylem vessels (Raliya *et al*., 2016)

transported into the plant by forming complexes with membrane transporters (Kurepa *et al.,* 2010). Corredor *et al.* (2009) revealed that nanoparticles can be entered in to the plant system and move to through the vascular system. Nanomaterials having the ability to enter from the atmosphere into the leaf stomata and then redistribute to the plant parts as observed by Wang *et al.* (2013) in watermelon plant and by Hong *et al.* (2014) in cucumber leaves (Fig. 1). Deepa *et al.* (2015) documented that calcium oxide nanoparticles (n-CaO) get transported via phloem tissue of groundnut.

In wheat plants nanoparticles were present in phloem tissues which mean that nanoparticles were taken up and transported through phloem route from leaves to stem down to roots, which was documented with transmission electron microscope (Abdel-Aziz *et al.,* 2018) and also observed by Wang *et al.* (2013) and Raliya *et al.* (2016) in watermelon plant (Fig. 2a and 2b). Nanoparticles with the diameter of less than 100 nm can easily penetrate through the stomata of leaves and were redistributed from leaves to stems through the phloem sieve elements (Wang *et al.,* 2013). Once the nanoparticle gets entered into the plant system which may be transported form one cell to other cell through plasmodesmata and carried by aquaporins, ion channels, endocytosis or by binding to organic chemicals (Rico *et al.,* 2011).

Polymers used into slow released nanofertilizer

Polymer helps to release the nutrients in a controlled manner, a character can be useful in the production of polymer coated nanofertilizer as smart fertilizer (Jatav and Nirmal, 2013; Manjunatha *et al.,* 2016). Swati Pund and Amita Joshi (2017) reviewed that polymeric nanoparticles have a matrix architecture composed of biodegradable and biocompatible polymers of synthetic or natural origin. The most widely used synthetic polymers are polylactide, polylactide - polyglycolide copolymers, polycaprolactones and polyacrylates. Among the various natural polymers, alginate, albumin or chitosan have been widely explored. The biodegradable, polymeric chitosan nanoparticles with the size of 78 nm were used for the controlled release of NPK fertilizer (Corradini *et al*., 2010). Sharmila Rahale (2011) reported that nano-clay based fertilizers (zeolite and montmorillonite) released the nutrient for a long period of time (>1000 hr) than conventional fertilizer (< 500 hr). Zeolite is natural mineral having extensive surface area and can hold wide range of positive and negetive nutrient ions after suitable partial modification (Desborough, 1996; Selva and Balakrishnan, 2017).

Kottegoda *et al.* (2017) produced the Urea-Hydroxyapatite nanohybrids for slow release of nitrogen and observed that nanohybrids strongly binds the urea, which released over longer period of time (up to one week) and the release rate was reduced by ~12 times compared to that of pure urea. Urea-encapsulated HA nanoparticles even on the day 60 the nanofertilizer was releasing nitrogen > 10 mg, clearly showing the efficacy of the slow release process. In case of commercial fertilizer, the release of nitrogen was within four days (Kottegoda *et al.*, 2011). Pereira *et al.* (2015) found that urea loaded polycaprolactone

Table Polymers used in the slow release formulation of fertilizer (Priscila *et al.*, 2017)

Fertilizer used	Polymer used	Reference
Urea	Chitosan	Hussain *et al.*, 2012
	Polyhydroxybutyrate (phb), ethyl cellulose	Costa *et al.*, 2013
	Polyethylene, polyvinyl acetate, polyurethane, polyacrylic, polylatic acid	Azeem *et al.*, 2014
KH_2PO_4	Chitosan, Gellan gum	Sabadini *et al.*, 2015
NPK	Chitosan	Noppakundilograt *et al.*, 2015
	Cellulose, natural gums, rosin, waxes	Lubkowski and Grzmil, 2007
	Parrafins, ester copolymers, urethane composites, alkide resins, polyolefines	Senna *et al.*, 2015
KNO_3	Chitosan	Melaj and Daraio, 2014
	Chitosan-clay (Montmorillonite)	Santos *et al.*, 2015
	Xanthan	Messa *et al.*, 2016

nanocomposites released the nitrogen for a long period of time (> 90 hr) over to conventional urea (< 25 hr).

Selva Preetha and Balakrishnan (2017) reviewed that releasing pattern of phosphorous fertilizer extended by the surface modification of fertilizer using various nanoclays and zeolite. Nano-formulations have been shown to release phosphate for an extended period of 40-50 days and the conventional fertilizer let out nutrients only upto 10-12 days. The review of literature suggests that surface modified zeolite could be potential strategy to promote phosphorus use efficiency which hardly exceeds 18-20 per cent in conventional system (Sharmila Rahale, 2011).

Effect of foliar fertilization of nanofertilizer on growth parameters

Growth

Nanofertilizers have important role in physiological and biochemical processes of crops by increasing the availability of nutrients, which help in enhancing metabolic processes and promoting meristematic activities causing higher apical growth and photosynthetic area. It was documented by some research studies, where 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) and also Abdel-Aziz *et al.* (2018) found that nano NPK increased the growth of leaves in wheat, which was obtained by enhanced availability of nutrients by easy penetration of nano formulation of NPK through stomata of leaves via gas uptake. Foliar applied nitrogen nanofertilizer increased the leaf dry weight of peppermint by 165 per cent over control (Rostami *et al.,* 2017).

Foliar application of zinc nano-fertilizer on pearl millet (*Pennisetum americanum* L.) significantly increased shoot length, root length, root area and plant dry biomass (Tarafdar *et al.,* 2014) and 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). Growth parameters like plant height, leaf number and fresh and dry weight of savory plant get increased by nano-zinc application (Vafa *et al.,* 2015). 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, protein metabolism, growth regulator metabolism, pollen formation and maintaining the integrity of biological membranes (Alloway, 2008; El-Tohamy and El-Greadly, 2007; Cakmak, 2000). Thus, the plant growth promoting harmone contents get increased with the application of nano Zn fertilizer.

Foliar application of nano-iron fertilizer increased the growth of forage corn and *Ocimum basilicum* L. because of enhanced production of crude protein and soluble carbohydrates (Sharifi *et al.,* 2016; Peyvandi *et al.,* 2011). The foliar spray of $nTiO_2$ increased the total drymatter production of plants by enhancing nitrogen assimilation, photo-reduction activities of photosystem II and electron transport chain and scavenging of reactive oxygen species (Morteza *et al*., 2013; Raliya *et al*., 2015). Janmohammadi *et al.* (2016) stated that foliar application of $nTiO_2$ had no any significant effect on number of fertile tillers in barley. Because, number of tillers in wheat and barley is mainly controlled by genetic factors and nutrition has a minor effect on this trait (Arora and Singh, 2004 and Bouis, 2003).

Physiological parameters

There was a remarkable increase in physiological and biochemical parameters of crops with the application of nanofertilizers. Biocompatible magnetic nanofluid had positive influence on the total chlorophyll content (a and b) in sunflower leaves. However, with higher concentrations (> 0.75 % MNF) the growth rate of the chlorophyll content is negative (Pirvulescu *et al.,* 2014). Foliar application of $nTiO_2$ has been recorded significantly higher chlorophyll content, carotenoids and anthocyanins of maize crop, which can facilitate an increase in corn yield (Morteza *et al.,* 2013). Janmohammadi *et al.* (2016) found that application of nanosized TiO_2 particles as a foliar spray positively influenced the some morphophysiological characters like days to anthesis and chlorophyll content of barley. In fact, $nTiO_2$ can improve structure of chlorophyll and helps better capture of sunlight, facilitates manufacture of pigments, stimulates rubisco activity and also increases photosynthesis. Nano formulation of TiO_2 improved spinach growth and also enhanced nitrogen metabolism, protein and chlorophyll contents (Yang and Hong, 2006). In another study, $nTiO_2$ had significantly increased chlorophyll content on the spinach leaves, and it was 17 times higher than the control plot, and also photosynthetic rate get increased by 29 per cent compared to control (Gao *et al.,* 2008).

Nano-chelate zinc fertilizer application proved to enhance the activity of peroxidase, catalase, and polyphenol oxidase enzymes in cotton and soybean crops which inceases the shoot and root growth (Rezaei and Abbasi, 2014; Weisany *et al.*, 2012). In pearl millet crop increased chlorophyll content, total soluble leaf protein and plant dry biomass were obtained with foliar application of zinc nano-fertilizer (Tarafdar *et al.*, 2014) and in savory plants the contents of chlorophyll, essential oil and phosphours were increased by nano-zinc application (Vafa *et al.,* 2015). Foliar application of zinc absorption by leaf epidermis and remobilization in to the grain through phloem and several membranes of zinc regulated transporters which might have regulated this process (Bashier *et al.* 2012; Mekkdad, 2017).

Nanofertilizer application increased the antioxidant potential in rice, antioxidants are secondary metabolites produced under unfavorable conditions faced by the plants such as water stress, salinity and limited nutrients. Moreover, nanofertilizer application was supplemental, its better absorption through plant cells somehow provided enough nutrients to enhance antioxidant activities (Benzon *et al.*, 2015). The cardioprotective, antimutagenic, and anticarcinogenic effects of phenolic compounds are reported to be generally associated with their antioxidant properties that eliminate free radicals and alleviate lipid peroxidation (Potter, 2005).

Yield

In the last few years, some researchers tried to examine the potential of nanofertilizers to increase the yield of crops. Foliar applications of nanofertilizer had reflected in improvement in yield parameters of wheat plants (Abdel-Aziz *et al.,* 2018). Foliar spray of NPK nanofertilizers 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 (Drostkar *et al.*, 2016). Application of nanofertilizers have greater role in enhancing cotton yield production besides reducing the cost of fertilizer and also minimizing the pollution hazard. Significant increases of total and open bolls per plant, boll weight and seed cotton yield with the foliar nanofertilizers application than soil application (Sohair *et al.,* 2018). Drostkar *et al.* (2016) suggested that foliar application of zinc, iron and NPK manipulates the growth of chickpea, resulting in beneficial effects on yield and yield components.

Tarafdar *et al.* (2014) reported that zinc nano-fertilizer applied as foliar spray on pearl millet (*Pennisetum americanum* L.) significantly increased the grain yield by 37.7 per cent and also Rezaei and Abbasi (2016) suggested that application of nano-chelate of zinc can improve cotton performance by increasing the number of bolls per plant and boll weight. Meena Dharam Singh, (2015) reported that seed oil content increased with increased concentration of nano ZnS in sunflower. In groundnut crop pod yield gets increased with the application of nano-scale zinc oxide compared to $ZnSO_4$ application, on account of nano-scale zinc is absorbed by plants to larger extent than its chemical form (Prasad *et al.*, 2012). Meena Dharam Singh and Aravinda Kumar, 2017 revealed that 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). The required dosage of nano based Zn fertilizer had 10 folds less than the conventional $ZnSO_4$ (Dapkekar *et al.*, 2018). It was suggested that nanofertilizer application increased grain zinc content without affecting grain yield, protein content, spikelets per spike, 1000 kernel weight, *etc.,* owing to enhanced enzyme activity and carbohydrate metabolism leading to an an increased yield (Afshar *et al.,* 2014). Nano-scale zinc oxide particle at 40 ppm treatment was associated with increased rice grain yield and its components in mid tillering and PI stages (Ghasemi *et al.*, 2017). Foliar application of metal oxide nano-particles *viz.,*MgO, ZnO and CuO recorded more than 22, 33 and 18 per cent of seed cotton yield, respectively than control (Anon., 2016). In pomegranate, fruit yield and number of fruits per tree get increased with the foliar spraying of nano-scale zinc and boron fertilizers (34 mg B $tree^{-1}$ or 636 mg Zn $tree^{-1}$, respectively) (Davarpanah *et al.,* 2016).

Janmohammadi *et al.* (2016) 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 (Gao *et al.,* 2013) and it enhanced the photoassimilates supply in leaves (*i.e.,* increasing source capacity) which ultimately increased the yield attributes. The application of nanofertilizers improved fertilizer use efficiency and significantly increased the grain yield and straw yield of barley (Janmohammadi *et al.,* 2016). The application of $nTiO_2$ improved the photosynthetic complexes and nitrogen metabolism which led to increase in fresh and dry mass of plant (Gao *et al.*, 2013; Morteza *et al.*, 2013; Klingenfuss, 2014; Tarafdar *et al.*, 2014; Janmohammadi *et al.,* 2016). Morteza *et al.* (2013) 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. The use of iron nano-fertilizer on soybean crop improved the yield (Sheykhbaglou *et al*., 2010). 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). Delfani *et al.* (2014) 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. Nano-Fe fertilizer application at tillering and stem elongation did increase the number of seeds per spike, whereas early application of Fe fertilizer decreased the number of seeds per spike in wheat. Hence, the foliar application of Fe was more suitable than seed dressing or soil application attributable to being a suitable time for seed formation. In addition, Fe availability can increase the leaf area index, leaf area duration, and decreased leaves senescence that can increase economic yield (Armin *et al.,* 2014). In another study, Jaberzadeh *et al.* (2013) recorded 23.3 per cent increase in grain yield with a foliar application of 2 per cent Nano-Fe over the control.

Spraying of manganese nanoparticles has been shown to increase growth, yield and its components compared with manganese sulphate on *Vigna radiata* (L.) Wilczek (Ghafariyan *et al*., 2013). Application of 30 ppm nano iron, manganese and zinc fertilizers produced maximum values of yield and yield attributes of peanut (El-Metwally *et al*., 2018) by reason of increased nutrient use efficiency of nano-fertilizers which enhance pigments formation, photosynthesis rate, dry matter production and thus leading to better growth and yield (Quary *et al.,* 2006; Hediat, 2012; Mekkdad 2017). The tuber yield of potato increased with the foliar application of nanosilver possibly by reason of its antimicrobial effect which might have helped seed tubers to stay healthier for longer time in the soil and subsequently produced more vigorous plants (Tahmasbi *et al.,* 2011). Foliar applied nano chelate molybdenum has a significant effect on the traits such as plant height, number of pods per plant, number of ripe pods per plant, hundred seed weight, seed number per plant, seed length and seed and pods yield and the number of lateral branches and the biological performance of peanut (Mehrangiz *et al.*, 2014).

Quality

Nutrients are required for improving the quality parameters of crops. In this aspect, nanofertilizer application gave better quality of crop products than the conventional fertilizer, which was supported by some research studies. Fibre quality parameters of cotton like uniformity ratio and fibre strength were improved by the application of metal oxide nanoparticles than control (Anon., 2016). Prasad *et al.* (2012) found that the application of fertilizer in nanoform is completely controlled and has led to an increase yield and protein content in peanut. Foliar application of nano-forms of iron and zinc fertilizers increased the phosphorus concentration, biomass, and crude protein and soluble carbohydrate concentration in forage corn over chemical forms of fertilizers, (Sharifi *et al.,* 2016). It was suggested that a positive close relationship between protein concentration and the concentration of iron and zinc in corn. Sham (2017) reported that foliar application of ZnO nanoparticles increased the quality parameters like oil content in sunflower. Zinc fertilizers increased soluble carbohydrate concentration, probably due to involvement of zinc in photosynthesis, chlorophyll synthesis, starch formation and enzyme carbonic anhydrase, accelerating carbohydrate formation (Singh and Kumar, 2012; Soleymani *et al.,* 2012; Sharifi *et al.,* 2016). In peanut, total carbohydrate, total soluble sugars, protein and oil percentages in seeds increased by nanofertilizers (El-Metwally *et al*., 2018). In protein content zinc element had an additive role for protein formation that showed an important role in the protein content of plants (Safyan *et al*., 2012).

Zinc plays a positive role in root develepment, which helps plants absorb important nutrients, especially nitrogen responsible for protein synthesis. Additionally, zinc is involved in the metabolism of carbohydrate, protein and plant hormones especially IAA and helps in the formation of starch and seed maturity (Fageria *et al*., 2002; El-Metwally *et al*., 2018). Nano-Fe appreciably influenced the seed protein content by 2 per cebt compared to common Fe in black-eyed pea (Delfani *et al*., 2014). Ashpakbeg Jamadar (2016) reported the positive effect of foliar applied NPs which enhanced the zinc uptake in upland paddy by 48 per cent over control and enzyme activity by 53 per cent.

Alleviation of abiotic stress

Abiotic stresses include salinity, drought, heavy metals, flooding, chilling, freezing, heat, ozone and ultraviolet radiation. Among abiotic stresses salinity and drought represent a great threat to crop production all over the world. These abiotic stresses including drought and salinity may cause a loss in crop production about 50 per cent (Wang *et al.,* 2003). Salinity causes nutrient imbalance, membrane damage and enzymatic inhibition in the plants by ionic and osmotic stress (Hasanuzzaman *et al*., 2013). In addition, soil salinity negatively interferes with the water availability to plants, absorption of essential nutrients and crop yields and qualities (Grattan and Grieve, 1999). One of the most important solutions is to use the nanomaterials in alleviating the harmful effects of these stresses.

Nanomaterials may mimic the role of antioxidative enzymes like peroxidase, superoxide dismutase and catalase. These antioxidants and enzymes are continuously scavenging the reactive oxygen species (Upadhyaya *et al*., 2015). Soil salinity declines growth parameters, *i.e.* dry matter, uptake of N, P, K, Na and Ca and yield of cotton. Under saline conditions the growth of roots affected, which reduces the nutrient uptake. Application of nano Zn enhanced the root penetration and increase uptake of nutrients as reported by Hussein and Abou-Baker (2018) and it caused significant changes in fresh and dry weight of rice (Upadhyaya *et al.* 2015), in biomass production of sunflower (Torabian *et al.,* 2016), in grain yield of wheat under salinity stress (Babaei *et al.,* 2017) and in yield of maize under drought (Farnia *et al.,* 2015). Soliman *et al.* (2015) reported that the salt stress can be alleviated in *Moringa* plants using foliar applications of ZnO and Fe_3O_4 NPs-containing Hoagland solution by enhancing enzyme activity related to salt tolerance. Accumulation of less Na is an important Indicatior of salt tolerance in plants. Potasium (K) content reflects salt tolerance in plants alleviating the adverse effects of NaCl on nutrients uptake through improving root growth and preventing nutritional disorders and increasing in nutrients uptake by the roots (El-Fouly *et al*., 2002). Because of larger specific surface area and more reactive areas of nanoparticles helped in enhanced enzyme activity related to salt tolerance. The nanoparticles (NP) simplify the absorption of fertilizer and enhances the effect of hoagland solution by increasing the avialabilty of Fe and Zn, which are involved in the salt tolerance mechanism. The foliar application of 200 ppm nano-Zn to the cotton crop under stress condition helps to increase the cotton growth and yield (Hussein and Abou-Baker, 2018).

The application of SiO_2 nanofertilizer 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 SiO_2 nanoparticle as foliar application avoided leaching loss of N and helped in more accumulation of nitrogen in leaf (Siddique, 2014). Foliar applied SiO_2 might help in increasing cell wall turgidity, strength and also cell wall elasticity during growth extension (Yassen *et al,* 2017). Also, Zurccani (2008) found that application of Si counter the negative effects of salinity in *Phaseolus vulgaris* L. by decreasing in stomatal conductance and increasing antioxidative enzymes activity.

Jaberzadeh *et al.* (2013) reported that water deficit stress caused significant decrease in plant growth, yield and yield components. In addition, application of titanium dioxide nanoparticles at 0.02 per cent increased the growth of wheat crop. Thus, the application of titanium dioxide nanoparticles under conditions of water deficit stress is recommended. Titanium improves rubisco activity and increases the CO_2 metabolism, increases photosynthesis and improves yield (Gao *et al.*, 2006). Generally under water stress condition gluten and starch content of wheat get reduced, the application of nano TiO_2 improves these contents may be due to the positive correlation between titanium application and photosynthesis rate (Zhao *et al.,* 2009; Jaberzadeh *et al.,* 2013). 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).

Alleviation of heavy metals toxicity

Nanofertilizers may be more effective than regular fertilizers in improving plant nutrition, enhancing nutrition use efficiency, and protecting plants from environmental stress. The cadmium (Cd) generally decreases the growth and the contents of Mg, Fe, Zn, chlorophyll a, and glutathione (GSH) particularly when accompanied by a significant increase in Cd accumulation (Wang *et al*., 2012). Foliar application with 2.5 mM nano-silicon alleviated Cd stress in rice seedlings as a result of enhanced the availability of Mg, Fe, and Zn nutrition, and the contents of chlorophyll a and decreased Cd accumulation and translocation of Cd from root to shoot (Wang *et al.,* 2014). The Cd treatment produced oxidative stress to rice seedlings indicated by a higher lipid peroxidation level and enhanced antioxidant enzymes activity such as superoxide dismutase (SOD), peroxidase (POD), and catalase (CAT), and a lower glutothionine (GSH) content. However, those nano-Si-treated plants had lower malondialdehyde (MDA) but higher GSH content and different antioxidant enzyme activities, indicating a higher Cd tolerance in them (Shi *et al.,* 2010; Zeng *et al.*, 2011; Wang *et al*., 2011).

Commercial nanofertilizer

Now-a-days, some fertilizer companies are producing nanfertilizers commercially. In cotton the growth and yield gets increased with the foliar application of commercial nanofertilizer nanomol than the other commercially available nanofertilizers *viz.,* Richfield, Agriklik and Nualgi. Unlike combined nutrient nanofertilizers, single micronutrient nanofertilizers *viz.,* Nanobor, Nanomag and Nanozinc also showed the positive results on number of bolls, boll weight and seed cotton yield (Anon., 2016). Moreover, 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).

In another trial, 10 per cent nano NPK fertilizer which is commercial one, treated as a foliar spray on wheat crop improved the quality of wheat grain (Abdel-Aziz *et al.*, 2018). 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 (Gomaa *et al.*, 2016) and also in maize crop (Gomaa *et al.,* 2017).

Phytotoxicity

Few studies have reported negative effects of nanoparticles on higher plants. The deposition of nanoparticles like titanium oxide, zinc oxide, cerium oxide, and silver nanoparticles on the surface of cell and in the organelles can cause oxidative stress to the cell by the stimulation of oxidative stress signaling (Buzea *et al.,* 2007). Foliar application of Fe_3O_4 nanoparticles on maize crop at high or low concentration affects the photosynthesis as well as interfere with the plasma membrane ion channels (Racuciu and Creanga, 2007). Tan *et al.* (2009) observed that in *Oryza sativa* with the application of multi-walled carbon nanotubes (MWCNTs), which increased the production of reactive oxygen species (ROS) and oxidative stress caused by Fe_3O_4 nanoparticles in the shoots and roots of cucurbits as observed by Wang *et al.* (2011). Some research suggested that with the application of Ag-NPs, which interfered membrane proteins and activate signaling pathways, that led to inhibition of cell proliferation (Roh *et al.,* 2012; Kumari *et al*., 2009; Gopinath *et al.,* 2010) and one more study conducted by Dimkpa *et al.* (2013) suggested that higher concentration of Ag application causes the accumulation of Ag in shoots. Increasing of Ag ions produces reactive oxygen species (ROS) that leads to oxidative stress, which reduces the root and shoot growth of wheat.

Nano-Mg demonstrated to give the greatest PMDI (plasma-membrane which damages index), suggesting that the application of nano-Mg would be harmful to the membrane of black-eyed pea (Delfani *et al.,* 2014). In drought conditions, applied nanofertilizers in rice alter the gene expression for protein synthesis during grain development (Mushtaq *et al.*, 2008). An investigation by Liu *et al.* (2008) revealed that foliar application of nanofertilizer on wheat decreased the protein content and increased the fat content.

Negative effects on human

Nanoparticles can easily enter into the biological systems which is not possible for the larger particles. Nanoparticles may cross cell membrane which depends on the dimension of nanoparticle. There is a possibility to inhale the nanoparticles by farm workers while spraying, which can reach the blood and may reach other target sites such as brain, liver or heart (Steve Suppan, 2017). These nanoparticles might affect the regulatory mechanisms of enzymes and other proteins (Bhushan, 2007). There is a chance of nanoparticles entering into the food chains which ultimately affects the human health system. Hence, there is an urgent need to develop human resources with an understanding of the complexities of the agricultural production system to serve nanotechnology applications in agriculture successfully (Siddhartha, 2014).

Conclusion

The production of engineered nanomaterials is a scientific breakthrough in material design and the development of new consumer products. Application of nanotechnology in agriculture is still in its budding stage. However, it has the potential to revolutionize agricultural systems particularly where the issues on fertilizer applications are concerned. Application of different nanofertilizers have greater role in enhancing crop production. This will reduce the cost of fertilizer for crop production and also minimize the pollution hazard. Nanofertilizers are more soluble or more reactive and it can improve penetration through cuticle, which also performs controlled release and targeted delivery. Nanofertilizers improve crop growth, yield, quality and increased NUE, alleviate the abiotic stress and heavy metals toxicity. Meanwhile, there is awareness created on the risks of consuming and performing few operations rather than the benefits and effectiveness of the technology.

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