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Foliar Application of Nano Fertilizer in Agricultural Crops: A Review

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ABSTRACT

To meet the food requirement of a huge population the food grain production need to be enhanced accordingly. However, the goal of higher production must not come at the cost of heavy exploitation of natural resources. In order to attain higher yields, need of the hour is to develop and promote new technologies and reform agricultural research. Nanotechnology helps to improve agricultural production by increasing the efficiency of inputs and minimizing relevant losses. 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 Since the research work on nanotechnology in agriculture is at nascent stage there is a dearth of information on the response of nanomaterials application in crops. An effort has been made to review and extend the work done worldwide on foliar application of nano fertilizers in agricultural crops.

Key words: Crop growth, Nano fertilizer, Nutrient use efficiency, Yield.

Nanotechnology is a new emerging and fascinating field of science that permits advanced research and nanotechnological discoveries which could open up novel applications in the field of biotechnology and agriculture (Siddiqui *et al*., 2015). Nano sized fertilizers are the new frontier of nanotechnology towards a sustainable agriculture. 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 and quality.

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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). 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 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. 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. 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 from Fig 1) 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). 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, whereas for the stomatal diffusion the pore radius always exceeded 20 nm (Eichert and Goldbach, 2008; Pérez-deLuque, 2017 Fig 2).

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

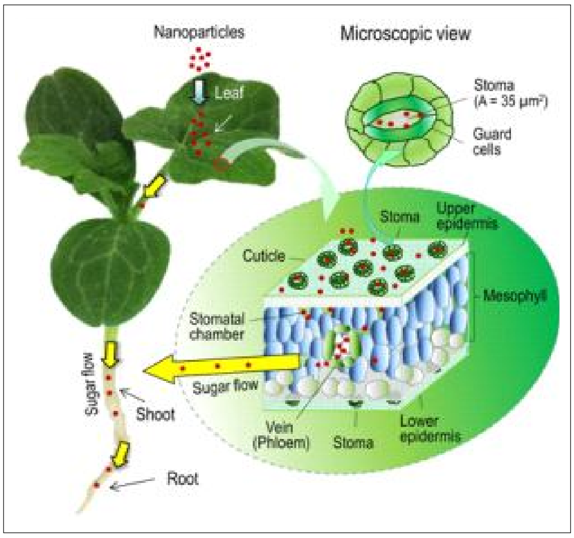
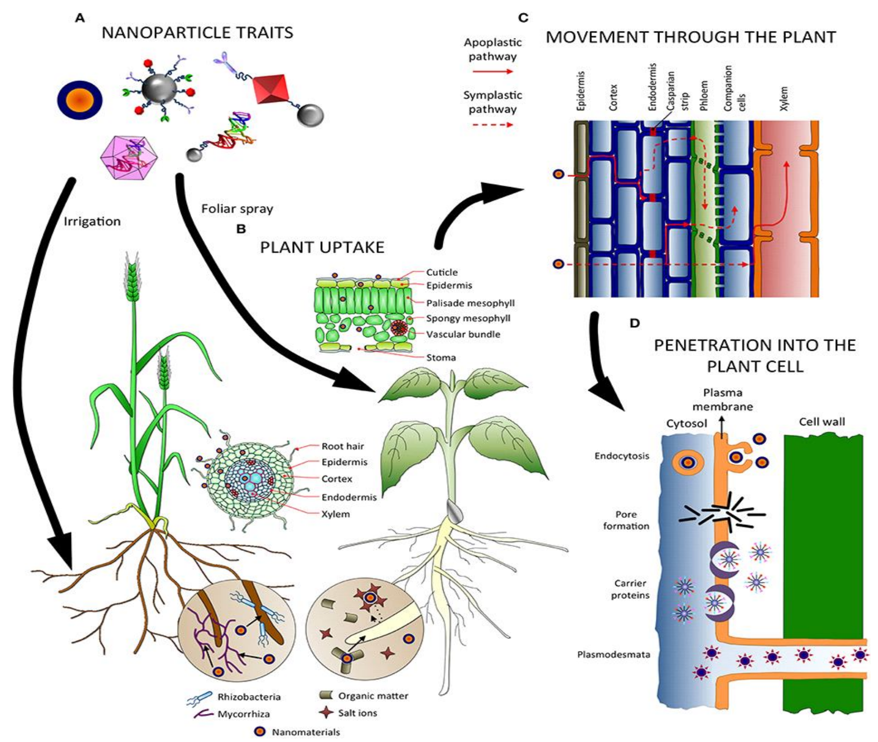


Fig 1: Mode of entry and translocation of foliar applied nanoparticles in to the watermelon plant (Wang *et al*., 2013).

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



(A) Nanoparticle traits affect how they are uptaken and translocated in the plant, as well as the application method. (B) In the soil, nanoparticles can interact with microorganisms and compounds, which might facilitate or hamper their absorption. Several tissues (epidermis, endodermis...) and barriers (Casparian strip, cuticle...) must be crossed before reaching the vascular tissues, depending on the entry point (roots or leaves). (C) Nanomaterials can follow the apoplastic and/or the symplastic pathways for moving up and down the plant and radial movement for changing from one pathway to the other. (D) Several mechanisms have been proposed for the internalization of nanoparticles inside the cells, such as endocytosis, pore formation, mediated by carrier proteins and through plasmodesmata, Pérez-deLuque (2017).

Fig 2: Factors influencing absorption, uptake, transport and penetration of nanoparticles in plants.

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).

Hayyawi *et al*. (2019) carried out experiment to study the response of Wheat to foliar application of nano-micronutrient (Iron, zinc and copper) as a single (mono) or in combinations. Treatments of nano-iron, nano-zinc, nano-copper and their traditional sources additional to a control. A number of plant and yield traits were studied. Results indicate significant response of the combined nano-(Fe+Cu+Zn) followed by the treatments of di and single spraying compared to control treatment with an increase of the triple foliar of 27.47, 28.53, 18.22, 141.23, 33.33 and 57.40% for plant height, length of spike, total chlorophyll SPAD, concentration of Cu, Zn and Fe, respectively compared to control treatment. The same treatment (tri) had grain yield and protein yield of 5.84 t ha^{-1} and 830.44 kg ha^{-1} compared to the treatment of triple of traditional fertilizers and control, which amounted to (4.55 and 3.60 t ha^{-1}) and (571.48 and 443.88 kg ha^{-1}), respectively. Harvest index were 51.05, 46.85, 48.73, 48.84, 40.57, 40.95, 43.71 and 37.89% for tri, di, single, control (Cu + Zn + Fe, Zn + Cu, Zn + Fe, Cu + Fe, Fe, Zn, Cu and control, respectively).

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 (2014) suggested that application of nanochelate of zinc can improve cotton performance by increasing the number of bolls per plant and boll weight.

Meena, (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 and 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 nanoparticles 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 nT_iO_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 T_iO_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.) (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).

Zareabyaneh and Bayatvarkeshi (2015) studied the effect of slow released fertilizers made by nanotechnology on nitrate leaching and its distribution in the soil profile compared with urea fertilizer in potato cultivation. The results of variance analysis showed that each treatment had a significant effect on yield and leaching and soil nitrate. So that soil nitrate during the growing season of potato in nano-nitrogen chelate (NNC), Sulfur-coated nano-nitrogen chelate SNNC and sulfur-coated urea (SCU) fertilizers were 10.36%, 29.92% and 23.95% more than urea (U) fertilizer, respectively. Hayyawi *et al*. (2018) conducted experiment to study the effect of foliar application of different sources of nano-fertilizers on growth and yield of wheat, they noticed that significant response was spraying of SMP nano-fertilizer followed by the spraying combined of tri (N+P+K), di (N+P), (N+K) and (P+K) nano-fertilizer compared to control and traditional (NPK+TE) fertilizer treatments respectively in all growth and yield parameters of wheat with an increment of the spray foliar (SMP) of 87.77 cm, 12.22 cm, 58.22 SPAD, 3.17%, 0.66% and 2.88% for plant height, length of spike, total chlorophyll, concentration of N, P and K respectively compared to control treatment.

Dimkpa *et al*. (2020) demonstrated that coating urea with ZnO-NPs enhances plant performance and Zn accumulation, thus potentiating field-scale deployment of nano-scale micronutrients. Notably, lower Zn inputs from ZnO-NPs enhanced crop productivity, comparable to higher inputs from bulk-ZnO. This highlights a key benefit of nanofertilizers: a reduction of nutrient inputs into agriculture without yield penalities.

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 (Anonymous, 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 and Shahrajabian, 2009; 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 cent 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.

Ghafari and Razmjoo (2013) investigated the effects of foliar application of nano-iron oxide (2 and 4 g L^{-1}), iron chelate (4 and 8 g L^{-1}) and iron sulphate (4 and 8 g L^{-1}) on grain yield, yield components and quality, foliar chlorophylls and carotenoids contents, peroxidase (POX), catalase (CAT) and ascorbate peroxidase (APX) activities of bread wheat

(*Triticum aestivum* L.) and observed that Fe fertilization increased antioxidant enzymes activities and chlorophylls contents, yield, yield components and the grain quality of wheat, however, application of 2 g L^{-1} nano iron oxide was more effective than other sources.

Nutrient use efficiency

Fertilizer being the major determinant of yield has gained much attention in research since long time. Though the research has achieved high productivity still the nutrient use efficiency is surprisingly low. nutrient use efficiency is surprisingly low.

Subhramanian *et al*. (2015) reported that the nutrient use efficiency of N, P and K stand still at 30-35%, 18-20% and 35-49% respectively. A study by Vellinga and Andre (1999) found only relatively small changes in NUE between different soil types. Their data also showed changes in NUE over time and proposed they were due to the development of new wheat varieties and their adaptations to soil conditions. However, it is more widely accepted that changes in soil types, textures and their interactions with management will influence nitrogen utilization and use efficiencies (Quan Bao *et al*., 2007) The concept of nitrogen use efficiency (NUE) is relatively new. Early definitions of NUE simply stated that it was the inverse of nitrogen concentration in the plant tissue (Chapin, 1980). Wheat generally loses about 20% of its nitrogen (Daigger *et al*., 1976). The nitrogen may be lost either by leaking it into the soil from the roots or by gaseous release from the stem and leaves in the form of ammonia or nitrogen oxides. Plants that have high NUE should also be able to retain more nitrogen in the plant and subsequently use it for grain production.

Several studies show that NUE in wheat is also dependent upon the prior crop that was grown in the field (Rahimizadeh *et al*., 2010). Crop rotations, especially when growing wheat, are highly recommended as they reduce the possibility of disease carryover between seasons. In a study by Rahimizadeh *et al*. (2010) they found evidence showing a wheat on-wheat monoculture system had the lowest NUE compared to more diverse rotations. They grew several other crops such as corn, clover, sugar beet and potato. The wheat-potato rotation provided the highest NUE value, which was 24% higher than the continuous wheat system. This study is also supported by Yamoah *et al*. (1998) who found strong evidence that the preceding crop can significantly affect the nitrogen use efficiency of wheat. All agriculture depends on weather. Not only is it difficult to predict, but it is impossible to control and can either help or hinder crop growth and NUE. During years of drought, applying nitrogen fertilizer to wheat can actually reduce grain yield. This, coupled with fertilizer costs, can be very detrimental for a farmer (Sadras, 2012). In contrast, too much water is also problematic, as it 16 can cause nitrogen to runoff, denitrify, or leach through the soil profile where 20 plants cannot use it (Asseng *et al*, 2001). The appropriate weather conditions for an area to promote high NUE are largely dependent on the soil type and management factors. There are 12 major soil orders in the world and within each one is thousands of different types. Each of these thousands of soils differs in its physical and chemical characteristics, which can interact with management factors and NUE.

Golada *et al*. (2013) studied the different levels of nitrogen 60, 90, 120 kg N/ha increase nitrogen levels up to 90 kg N/ha mark ably improved the yield attributes, yield and net returns. Application of 90 and 120 kg N/ha exhibited significant increase in green cob yield over 60 kg N/ha. The results revealed that application of nitrogen up to 90 kg N/ha level significantly increased green cob yield and baby corn yield in tune of 20.5 and 23.6% as compared to 60 kg N/ha. Rahman *et al*. (2014) stated that the foliar applications is the technique of feeding plants by spraying liquid fertilizers or other chemical or natural product directly to the leaves of macro and micronutrients are more effective in term of getting maximum yield and reduce losses.

Jhanzab *et al*. (2015) studied the role of Silver Nano Particles (SNPs) for improving nutrient use efficiency (NUE) in wheat and showed that SNPs significantly enhanced most of the growth and yield attributes NPK uptake and nutrient use efficiency of wheat. Silver nanoparticles in 25 ppm concentration have showed significant improvement in maximum leaf area and highest grain yield while 75 ppm concentration resulted in decrease in grain yield. So silver nanoparticles have stimulatory as well as inhibitory effect on wheat growth and yield.

Xu *et al*. (2019) carried out a 17-year experiment in a semiarid area of the Loess Plateau of China to assess the effects of N fertilization on spring wheat (*Triticum aestivum* L.) grain yield, N uptake, N utilization efficiency and residual soil nitrate and showed that the concentration of NO_3-N in the 0-110 cm depth soil layers was significantly affected by N application, with higher N rates associated with greater soil NO_3-N concentration. With the annual application of N over 17 years, residual soil NO_3-N concentration in the 100-200 cm soil layer in the last study year was significantly greater than that in the non-N-fertilized control and was increased with rate of N application. There was a significant positive relationship of soil NO_3-N in the 0-50 cm and 50-110 cm soil layers at wheat sowing with wheat grain N content and yield. Wheat grain yield in the third year (2005) was significantly, *i.e*., 22.57-59.53%, greater than the unfertilized treatment after the N application was stopped. Nitrogen use efficiency decreased in response to each increment of added N fertilizer and was directly related to N harvest index and grain yield. Therefore, greater utilization of residual soil N through appropriate N fertilizer rates could enhance nitrogen use efficiency while 17 reducing the cost of crop production and risk of N losses to the environment. For these concerns, optimum N fertilizer application rate for spring wheat in semiarid Loess Plateau is about 105 kg N ha^{-1}, which is below the threshold value of 170 kg N ha^{-1} per year as defined by most EU countries.

CONCLUSION

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. 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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