International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2018; 6(5): 755-760

Received: 15-07-2018
Accepted: 20-08-2018

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Application of nanotechnology in precision farming: A review

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Abstract
In the current paper, we reviewed the use of nanotechnology based products and its application in agriculture. Growing realization that conventional farming technologies would neither be able to increase productivity any further nor restore ecosystems damaged by existing technologies has paved the pathway to application of nanotechnology in agriculture. Nanotechnology has many applications in all stages of production, processing, storing, packaging and transport of agricultural products. This technology will revolutionize agriculture and food industry by innovation new techniques such as Precision farming techniques, controlled release of agrochemicals and site targeted delivery of various macromolecules needed for improved plant disease and pest resistance, efficient nutrient utilization and enhanced plant growth. Processes such as nano encapsulation show the benefit of more efficient use and safer handling of pesticides with less exposure to the environment that guarantees eco protection.

Keywords: nanotechnology, nano-fertilizers, nano-herbicides, nanobiosensor

1. Introduction

Nanotechnology, deals with the matter at nanoscale (1-100 nm), is commonly referred as a generic technology that offers better built, safer, long-lasting, cost effective and smart products that will find wide application n household, communication, medicine, agriculture and food industry etc. Nanotechnology is recognized by the European Commission as one of its six ‘‘Key Enabling Technologies’’ that contribute to sustainable competitiveness and growth in several fields of industrial application in current era after industrial revolution of 1700s, nuclear energy revolution of the 1940s, the green revolution of 1960s, information technology revolution of 1980s, and biotechnology revolution of 1990s.(EU, 2012). It is an emerging and fast growing field of science which is being exploited at a wide spectrum of disciplines such as physics, biology, material sciences, electronics, medicine, energy, environment and health sectors. Materials reduced to nanoscale show some unusual properties which is different from what they exhibit on macro scale, leading to unique applications. Nanotechnology has revolutionized in different fields in achieving the processes and products that are hardly possible to be evolved through conventional systems. Nanotechnology aided application have the potential to change agricultural production by allowing better management and conservation.

2. Precision farming

Agriculture are the basis of providing food, feed, fiber, fire and fuels. In the future, demand for food will increase tremendously while natural resources such as land, water and soil fertility are limited. The cost of production inputs like chemical fertilizers and pesticides is expected to increase at an alarming rate due to limited reserves of fuel such as natural gas and petroleum. In order to overcome these constraints, precision farming is a better option to reduce production costs and to maximize output, i.e. agricultural production. The process of maximizing crop yields and minimizing the usage of pesticides, fertilizers, and herbicides through efficient monitoring procedures is referred to as precision farming.

However in the field of agriculture, the use of nanomaterials is relatively new and needs further exploration. This technology holds the promise of controlled release of agrochemicals and site targeted delivery of various macromolecules needed for improved plant disease resistance, efficient nutrient utilization and enhanced plant growth Nanotechnology based products and its application in precision agriculture include nano-fertilizers, nano-herbicides, nano-pesticides, nano-scale carriers, nano sensors, detection of nutrient deficiencies etc. this fast growing technology is already having a significant commercial impact, which will certainly increase in the future.

3. Synthesis of nanoparticles

Synthesis of nanoparticles involves a number of chemical, physical, aerosol and biological methods including chemical reduction in aqueous or non-aqueous solution, micro emulsion (Solanki *et al*.2010) [33], template (Chen *et al.* 2002) [6], son chemical (Pol *et al*. 2002) [24], microwave assisted. Physical and chemical methods have been utilized for the synthesis of nanoparticles (Mandal *et al*. 2005; Solanki and Murthy 2010; Huang *et al*. 2011) [33, 11]. Physical synthesis include sedimentation process, rotor speed ball mill, high energy ball mill and pot mill. For example phosphorus (P) nanoparticles are prepared by purifying rock phosphate and grinding with high energy mill. Chemical method include precipitation and poly vinyl pyrolidine (PVP) techniques. Basically, the physical methods have affected low yields, while the chemical ones caused harmful effects on the environment due to use of toxic solvents and the regeneration of hazardous by-products (Wang *et al*. 2007). Different biological sources have been used for the synthesis of nanoparticles and are being used in agriculture for precision farming [11]. Some of them are as follows: silver nanoparticles, zinc oxide nanoparticles, titanium dioxide nanoparticles. Microorganisms have been explored as potential bio-factories for synthesis of metallic Nanoparticles such as cadmium sulphide, gold, and silver (Sastry *et al*. 2003) [29]. Biological nanoparticle can be prepared by selecting microorganism to grow in a particular salt solution after preparation of microbial balls. Fungal mediated biosynthesis of nanoparticles (Raliya R. 2012). Biosynthetic methods have been investigated as an owing to ecofriendly environment concern and reduced agglomeration. (Roy *et al*. 2013; Emeka *et al*. 2014).

Uptake of nano-particles in plant system

Nanoparticles are adsorbed to plant surface and taken up through natural nanometer plant opennings. Several pathways exist or predicted for nanoparticles association and uptake in plants. Nanoparticle uptake into the plant body can use different paths. Uptake rates will depend on the size and surface properties of the nanoparticles. Very small sizes nanoparticles can be penetrate through cuticle. Larger nanoparticles can penetrate through cuticle-free areas, such as hydathodes, the stigma of flowers and stomata's. Nanoparticles must traverse the cell wall before entering the intact plant cell protoplast. Result suggests that only nanoparticle less than 5 nm in diameter will be able to traverse the cell wall of undamaged cell efficiently.

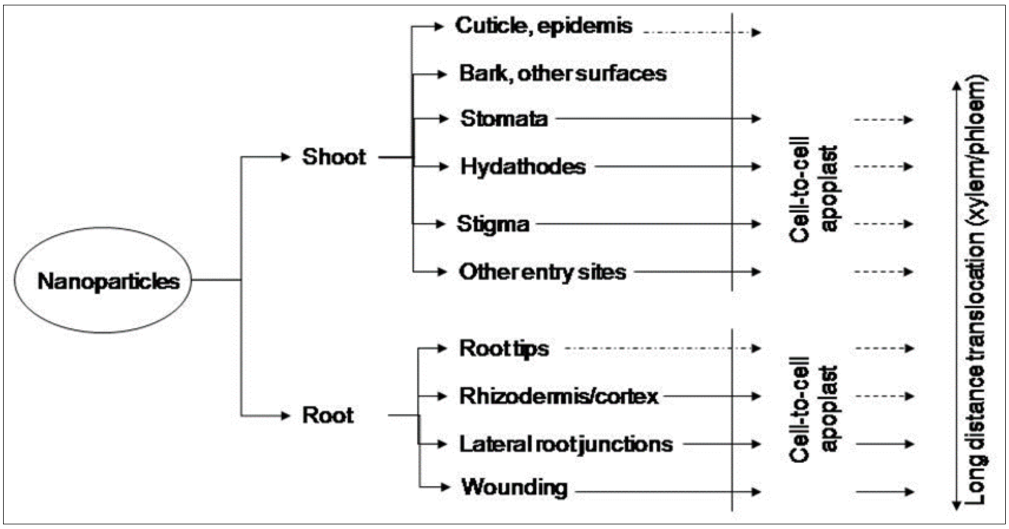

Fig 1

4. Application of nanoproducts in precision agriculture

4.1 Plant germination and growth

Seed is a basic input which decide the fate of productivity. Traditionally, seeds quality is determined by their germination percentage. Despite recording higher germination percentage (80-90%) in laboratory, seeds shows lower germination percentage in fields. In recent years, various researchers have studied the effects of nanomaterial's on plant germination and growth with the goal to promote its use for agricultural applications.

Zheng *et al*. (2005) [40] studied the effects of nano and non-nano TiO2 on the growth of naturally-aged spinach seeds. It was reported that nano-TiO2 treated seeds produced plants that had 73% more dry weight, three times higher photosynthetic rate, and 45% increase in chlorophyll a formation compared to the control over germination period of 30 days. The growth rate of spinach seeds was inversely proportional to the material size indicating that smaller the nanomaterial's the better the germination. The key reason for the increased growth rate could have been the photo-sterilization and photo-generation of "active oxygen like superoxide and hydroxide anions" by nanoTiO2 that can increase the seed stress resistance and promote capsule penetration for intake of water and oxygen needed for fast germination. The authors concurred that the nano size of TiO2 might have increased the absorption of inorganic nutrients, accelerated the breakdown of organic substances, and also caused quenching of oxygen free radicals formed during the photosynthetic process, hence increasing the photosynthetic rate. Khodakovskaya *et al.* (2009) at university of Arkanasas, USA, used carbon nano-tube for improving the germination of tomato seeds. The reason for the result is that carbon nano tube served as new pore for water permeation by penetration of seat coat and act as gate to channelize the water from the substrate in the seeds. This method can be utilized in rainfed ecosystem. Dimkpa *et al*. (2015) found that ZnO NPs at 100 mg/kg dose stimulate shoot growth of common beans (Phaseolus vulgaris). Enhanced growth of mung bean and chickpea (Cicer arietinum) seedlings at low concentrations using zinc-oxide nanoparticles with plant agar method were observed, however a decline in growth rates of roots and shoots were observed beyond optimal concentrations (Mahajan *et al.* 2011) [16]. Manganese nanoparticles have been also reported to enhance growth of mung bean (Vigna radiata) and photosynthesis (Pradhan *et al.* 2013) [21]. Foliar application of 500 mg L−1 iron nanoparticles to black-eyed peas significantly increased the number of pods per plant (by 47%), weight of 1000-seeds (by 7%), the iron content in leaves (by 34%), and chlorophyll content (by 10%) over those of the controls. Application of iron nanoparticles also improved crop performance more than that by application of a regular iron salt. These parameters were increased by 28%, 4%, 45%, and 12%, respectively, under the iron nanoparticles treatment compared with these under treatment with iron salt (Delfani *et al.* 2014) [7]. These results revealed that application nanoparticles could be used to significantly enhance seed germination potential, seed germination index, seed vigor index, seedling fresh weight and dry weight.

4.2 Nano fertilizers for balanced crop nutrition

At present in agriculture, fertilizer contributes to the tune of 50% of the agricultural productivity of any crop. Increasing use of higher doses of fertilizers does not guarantee to improved crop yield but it leads serious issues like degradation of soil and pollution of surface and underground water resources. The use efficiency of N, P and K fertilizers remained constant as 30-35%, 18-20%, 35-40 respectively. Which means major portion of fertilizer added fertilizers stays in soils and enter the aquatic system causing eutrophication. Absorption of nutrients by the plants from soil can be maximized using Nano fertilizer. To increase food production, TiO2 or titanium that is non-toxic can be used as additives in fertilizers. The additives in fertilizers can increase water retention (Emadian *et al.* 2017) [9]. Thus, nano-fertilizers technology is very novel approach to address issues such as low fertilizer use efficiency, imbalanced fertilization. Nano fertilizers are advantageous over conventional fertilizers as they increase soil fertility yield and quality parameters of the crop, they are nontoxic and less harmful to environment and humans, they minimize cost and maximize profit. Naderi and Abedi (2012) [17] reported nano particles increases nutrients use efficiency and minimizing the costs of environment protection, improvement in the nutritional content of crops and the quality of the taste. Optimum use of iron and increase protein content in the grain of the wheat (Farajzadeh *et al.* 2009) [10]. Raliya (2012) [37] reported an enhanced production in pearl millet and cluster bean by foliar application of nanophosphorus fertilizers. He found that 640 mg ha^{-1} foliar application (40 ppm concentration) of nanophosphorus gives 80 kg ha^{-1} P equivalent yield. Batsmanova (2013) reported wheat plants grown from seeds which were treated with metal nanoparticles on average increased by 20–25%. Prasad *et al.* (2012) studied effect of nano Zn on peanut seeds treated with different concentrations of zinc oxide nanoparticles. Zinc oxide nanoscale treatment (25 nm mean particle size) at 1000 ppm concentration was used which promoted seed germination, seedling vigor, and plant growth and these zinc oxide nanoparticles also proved to be effective in increasing stem and root growth in peanuts. DeRosa *et al.* (2010) [30] has pointed towards Nano fertilizers impact on economy, energy, and environment due to reduction in nitrogen loss through leaching, emission and long term incorporation by microorganisms. Milani *et al. (*2012) used Macronutrient fertilizers coated with zinc oxide nanoparticles and reported enhancement of nutrients absorption by plants and the delivery of nutrients to specific sites. The adsorbents zeolite, halloysite, montmorillonite and bentonite nanoclays were used to develop nitrogen fertilizers with controlled release characteristics where nanoclay purification comes to be a costly affair except zeolite (Sharmila *et al.* 2010) [32].

4.3 Nano pesticides

Despite the fact that there are several available alternative methods, pest control is still largely based on the use of pesticides, but there are still concerns about their environmental impact. In this regard, pesticide use has been related with mammalian toxicity, environmental contamination, and bioaccumulation. ''Nano pesticides'' is a collective term for designing novel active ingredients with nanoscale dimensions, as well as their formulation and delivery. In order to protect the active ingredients from the environment conditions and to promote persistence, nanotechnology approach 'nano-encapsulation' can be used to improve insecticidal value. 'Controlled release of the active ingredients' approach is used to improve effectiveness of formulation. Liu *et al.* (2013) [12] used Porous hollow silica nanoparticles (PHSNs) loaded with validamycin (pesticide) as efficient delivery system of water-soluble pesticide for its controlled release. Nano-encapsulation comprises nano-sized particles of the active ingredients being sealed by a thin-walled sac or shell (protective coating). Sasson *et al.* (2007) listed some common benefits of NP-based pesticide formulations include: (a) increased solubility of water insoluble active ingredients, (b) increased stability of formulation, (c) elimination of toxic organic solvents in comparison with conventionally used pesticides, (d) capability for slow release of active ingredients, (e) improved stability to prevent their early degradation, (f) improved mobility and higher insecticidal activity due to smaller particle size, and (g) larger surface area which is likely to extend their longevity. A number of plant-synthesized NPs have been investigated for their efficacy against arthropod pests of economic importance, including moths (Roni *et al*. 2015), beetles (Abduz Zahir *et al*. 2012). Anjali *et al*. (2010) reported formulation of artificial polymer-free nano permethrin as an effective larvicide that was stabilized by plant extracted natural surfactants. More of such studies that investigate the use of natural stabilizers for nanopesticide formulations in agricultural plant protection are needed. Insecticidal activity of nanostructured alumina against *Sitophilus oryzae L*. and *Rhyzopertha dominica* reported significant mortality after 3 days of continuous exposure to nanostructured alumina-treated wheat. So, commercially available insecticides, inorganic nanostructured alumina may provide a cheap and reliable alternative for control of insect pests (Teodoro *et al.* 2010) [35].

4.4 Nanoparticles and plant disease control

Some of the nano particles that have entered into the arena of controlling plant diseases are nanoforms of carbon, silver, silica and alumino-silicates. At such a situation, nanotechnology has astonished scientific community because at nano-level, material shows different properties. Nano size silver particles as antimicrobial agents has become more common as technology advances, making their production more economical. Thus, use of nanoparticles has been considered an alternate and effective approach which is ecofriendly and cost effective for the control of pathogenic microbes (Kumar *et al.*2009) [14]. Properly functionalized Nano capsules provide better penetration through cuticle and allow slow and controlled release of active ingredients on reaching the target weed. The use of such nano-biopesticide is more acceptable since they are safe for plants and cause less environmental pollution in comparison to conventional chemical pesticides (barik *et al.* 2008) [3]. These nanoparticles have a great potential in the management of plant diseases compared to synthetic fungicides (Park *et al.* 2006) [19]. Nano silver is the most studied and utilized nano particle for bio-system. It has long been known to have strong Young (2009) [39] used nano size silver particles as antimicrobial agents and reported silver displays different modes of inhibitory action to microorganisms, it may be used for controlling various plant pathogens in a relatively safer way compared to commercially used fungicides. Pal *et al.* 2007 reported Silver affect many biochemical processes in the microorganisms including the changes in routine functions and plasma membrane. The silver nanoparticles also prevent the expression of ATP production associated proteins (Yamanka *et al.* 2005) [38]. In a nutshell, the precise mechanism of bio molecules inhibition is yet to be understood. noparticles from plants Production of nanomaterial's through the use of engineered plants or microbes and through the processing of waste agricultural products. Encapsulated nanosilica can form a binary films on the cell wall of fungi or bacteria after absorption of nutrients and prevent infections, hence improve plant growth under high temperature and humidity and to improve plant resistance to disease (wang *et al,* 2002) [37]. Silicon-based fertilizers used to increase plant resistance as silicon dioxide nanoparticles can improve seedling growth anroot development (Hutasoit *et al.* 2013) [12]. Zinc oxide (ZnO) and magnesium oxide (MgO) nanoparticles are effective antibacterial and anti-odour agents (Shah and Towkeer 2010) [30]. The increased ease in dispensability, optical transparency and smooth-ness make ZnO and MgO nanostructures an attractive antibacterial ingredient in many products. Both have also been proposed as an anti-microbial preservative for wood or food products (Sharma *et al.* 2009), inhibitory and bactericidal effects as well as a bro [31] ad spectrum of antimicrobial activities (Swamy and Prasad 2012) [23].

4.5 Nano-herbicide
Weeds are menace in agricultural production systems. Since two third of Indian agriculture is rainfed farming where usage of herbicide is limited. Herbicide available in market are designed to control, but none of the herbicide inhibit activity of belowground plant parts like rhizome and tubers. Nanotechnology can improve efficacy of herbicides, resulting in greater production of crops. Nanoherbicides can play a very important role in removing weeds from crops in an eco-friendly way, without leaving any harmful residues in soil and environment (A. Pérez-de-Luque *et al.* 2009) [20]. Encapsulation of herbicide in polymeric nanoparticles also results in environmental safety (Kumar *et al.* 2015) [13]. Developing a target specific herbicide molecule encapsulated with nano particles are aimed. for specific receptors in roots of target weeds, gets tranlocated in parts of weed that inhibit glycolysis of food reserve, (Chinnamuthu and Kokiladevei, 2007). Nano based adjuvants are also available for application. Bio-Based, 2010 reported a Nano surfactant based on soybean micelles to make glyphosate resistant crops. Toxicity of poly (ε-caprolactone) Nano capsules containing ametryn and atrazine against alga Pseudokirchneriella subcapitata and the micro crustacean

Daphnia similis has been tested. Herbicides encapsulated in the poly (ε-caprolactone) nanocapsules resulted in lower toxicity to the alga (Pseudokirchneriella subcapitata) and higher toxicity to the micro crustacean (Daphnia similis) as compared to the herbicides alone (Clemente *et al.* 2014) [5].

4.6 Biosensors
A sensor is a device built to detect a specific biological or chemical compound, usually producing a digital electronic signal upon detection. Precision farming utilizes remote sensing devices, computers and global satellite positioning systems to analyze various environmental conditions in order to determine the growth of plants under these conditions and identify problems related to crops and their growing environments. Through advancement in nanotechnology, a number of state-of-the-art techniques are available for the improvement of precision farming practices that will allow precise control at nanometer scale. The implementation of nanotechnology in the form of small sensors and monitoring devices will create a positive impact on the future use of precision farming methodologies. Nanotech-enabled systems help in increasing the use of autonomous sensors that are linked into GPS systems to provide efficient monitoring services focused on crop growth and soil conditions. The usage of smart sensors in precision farming will result in increased agricultural productivity by providing farmers with accurate information that will enable them to make accurate decisions related to plant growth and soil suitability.

Nanobiosensors are used in sensing a broad array of Precision farming, with the aid of smart sensors, could enhance productivity as this technology ensures better management of fertilizers, herbicide, pesticide, insecticide, moisture and soil pH. Which reduces input cost and environment safety Controlled use of biosensors can assist in sustainable agriculture for increasing crop productivity.. Nanosensors based smart delivery systems could help in the efficient use of natural resources like water, nutrients and agrochemicals by precision farming (Rai *et al.*2012) [26].

Quantum dots are efficient luminescence, small emission spectra, have excellent photostability and tenability according to the particle sizes and material composition. By a single excitation light source, QDs can be excited to all colors due to their broad absorption spectra (Warad *et al.* 2004) [36]. Quantum dots are used to detect pathogens associated with different plant diseases. Rad *et al.* (2012) [25] reported witches' broom disease (*Phytoplasma aurantifolia*). Safarpour *et al.* (2012) [25, 28] used QDs to detect beet necrotic yellow vein virus Polymyxa betae (Keskin), the only known vector of beet necrotic yellow vein virus.

4.7 Smart delivery system
Nanoscale devices are envisioned that would have the capability to detect and treat diseases nutrient deficiencies in crop long before symptoms were visually exhibited. "smart delivery systems" for agriculture possess-

- Timely controlled,
- spatially targeted,
- self-regulated,
- remotely regulated,
- pre-programmed,
- multifunctional characteristics

It can monitor the effects of delivery of nutrients or bioactive molecules or any pesticide molecules, this would allow judicious use of inputs.

5. Conclusion

This paper is based on the provision of basic knowledge about the applications of nanotechnology in precision agriculture and their prospects in the near future with reference to the current situation around the world. In this review, some of the potential applications of nanotechnology in precision agriculture for the welfare of humans and for sustainable environment, challenges and opportunities for developing countries have been identified. Nanotechnology will play a vital role in the development of the agricultural sector, as it is capable of being used in agricultural products that protect plants and monitor plant growth and detect diseases. Application of nanotechnology in agriculture, even at its global level, is at its nascent stage. Scientists have been working towards exploring new applications of nanotechnology in agriculture.

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