Water soluble carbon nanotubes increase agricultural yields.

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Abstract

The introduction of nanotechnology-based applications in agriculture is important to tackle the difficulties faced by agriculture and food sector across the globe. Nanomaterials facilitate controlled delivery of nutrients with increased crop protection. Due to their direct and indirect applications, nanomaterials can support the development of high-tech agricultural farms. This is exactly what is needed to maximize agricultural output by improvement of the ability of plants to absorb nutrients from the soil.

Keywords: Nanotechnology, Nanomaterials, Agriculture farms.

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Introduction

Carbon Nanotubes (CNTs) were first discovered independently by [1,2].They are cylindrical in shape and can be either single-walled (SWCNTs) or multi-walled (MWCNTs) [3]. As their name, 'Carbon Nanotubes,' implies, CNTs have diameters in the range of nanometers. Single-walled carbon nanotubes (SWCNTs) are less than 1 nm in diameter while multi walled carbon nanotubes (MWCNTs) have diameters in excess of 100 nm. Recent studies have shown the beneficial effects of CNTs on plants, both in vitro and in vivo [4]. These studies have shown that both MWCNTs [5] and SWCNT's can cross the cell walls of plant cells and can be transported to specific cellular organelles [6, 7].

Production of Water-soluble CNTs

One of the drawbacks pertaining to the use of CNTs in agriculture is their poor water solubility. Numerous approaches have been used to improve the solubility of CNTs in water [8]. In recent years, chemical modifications have improved the solubility of CNTs in water [9]. CNTs can be modified both covalently and non-covalently by introducing various functional groups on their outer surfaces [10,11]. One convenient method is the ozone-induced oxidation of CNTs in the gas phase [12]. In addition, the UV-ozone oxidative approach has also been used [13]. Another method for surface modification of CNTs uses air atmospheric pressure dielectric barrier discharge (APDBD) [14,16].

Advantages for the Use of Carbon Nanotubes in Agriculture

A number of different CNTs with differing sizes and properties have been used in plant systems [17]. They have been shown to influence both growth and development. The presence of CNTs in the soil can induce changes in metabolic functions of plants resulting in an increase in biomass and yield. Some studies have shown the effect of MWCNTs on seed germination and growth in radish (*Raphanus sativus*), rapeseed (*Brassica napus*), rye, lettuce, maize, and cucumber [18,19]. MWCNTs have been shown to have a positive effect on seed germination of *Brassica juncea L.* and *Phaseolus mungo L.* [20]. Similarly, Ma et al. investigated the effect that SWCNTs have on root growth of carrot (*Daucus carota*), cucumber, lettuce, onion (*Allium cepa*), and tomato [21,22]. Srinivasan found an increase in seed germination and growth rate in tomato seeds when exposed to CNTs [22]. A higher rate of germination was observed in hybrid Bt cotton (*Gossypium hirsutum*) [23], Indian mustard (*Brassica juncea*), urad bean (*Vigna mungo*), and rice (*Oryza sativa*) after treatment with MWCNTs [18,22,24]. In short, CNTs have been shown to be beneficial in agriculture as well as having possible use in other disciplines (Figure 1).

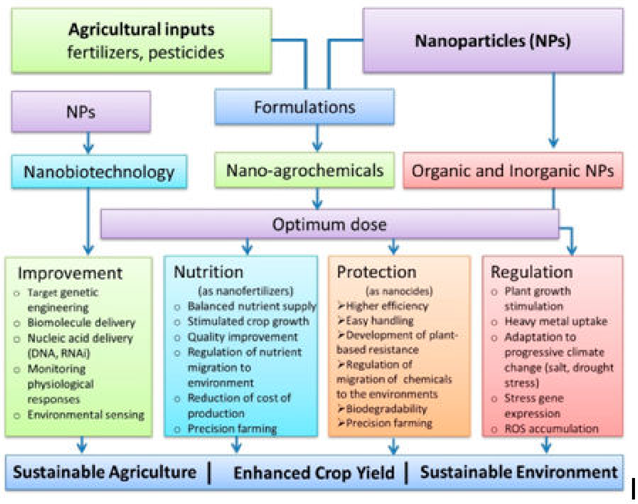

Figure 1: *Various applications of Carbon Nanotubes.*

Many studies have investigated the accumulation of CNTs in plants (Table 1). In 2007, Lin and Xing found that ryegrass

(*Lolium perenne*) increases in root length on exposure to MWCNTs. Canas et al. investigated the effect of uncoated-SWCNTs on cabbage (*Brassica oleracea),* carrot (*Daucus carota*), cucumber (*Cucumis sativus*), lettuce (*Lactuca sativa*), onion (*Allium cepa*) and tomato (*Lycopersicon esculentum*) [25]. CNTs have also been shown to more than double the growth rate of tobacco cell cultures [3]. A summary of the effect of CNTs on seed germination and plant development is shown in (Table 1).

Table 1: *Effect of CNTs on seed germination and plant development.*

Crops	Type of nanoparticles	Concentration (mgL)	effect
Wheat, maize, peanut, garlic, bulb	Water soluble MWCNTs	20,50	Enhanced germination
Barley, maize, soybean	MWCNTs	50,100,200	Enhanced germination
Barley, maize, soybean	MWCNTs	25,50,100 (spray)	At 25 mgL no effect; at 100 mgL increased germination rate
Tomato	MWCNTs	10,20,40	Increased seed moisture content; enhanced germination
Rice	CNTs	50,100,150	Enhanced germination
Rice	CNTs	n.a.	Increased seed moisture content; enhanced germination
Tomato, onion, turnip, radish	CNTs	10,20,40	Enhanced germination of tomato and onion

Production of Water Soluble Carbon Nanotubes-added Biofertilizer

Biofertilizers provide nutrients to the crops through nitrogen fixation and solubilizing of phosphates by the use of microbial inoculants. The microbes that are utilized in biofertilizer are first characterized in the laboratory. The steps involved in the production of biofertilizer include selection of a suitable bacterial strain, isolation of the bacteria and preparation of a carrier system followed by mixing, curing, packaging, storage and dispatching of product (Figure 2).

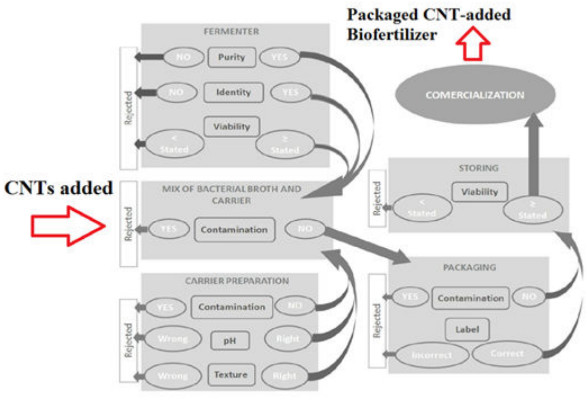

Figure 2: *Flow chart showing the different steps involved in the commercial production of CNT-added Biofertilizer.*

Mechanism of Action of Water Soluble Carbon Nanotubes

Most CNTs can be absorbed by plants [3]. However, the extent of their absorption depends on the plant species and the properties of CNTs being used [26]. The influence of CNTs can be neutral, positive or negative depending upon the concentration, chemical properties, structure and size of CNTs [27]. In some plants, biological pathways are affected by the interaction of CNTs at the gene level. The production of fruit is significantly accelerated by MWCNTs [28] but the absorption of MWCNTs can also lead to formation of vacuoles, shrinkage of cytoplasm and non-appearance of nuclei in some plants [29,30]. It has been hypothesized that water soluble CNTs enhance the capillary action of water absorption [31]. It is already known that there is water is present in xylem channels. The molecular transport takes place faster via xylem when water soluble CNT are present in water which results in very rapid flow of water, as predicted by molecular dynamics simulations [32].

Drawbacks for the use of Carbon Nanotubes

Some studies have provided information about toxicity possessed by CNTs [33]. However, very few studies have investigated the toxicity of CNTs in environmental conditions. One of the reasons why the toxicity displayed by CNTs is less understood is the low solubility and reactivity of CNTs with soil and background radiation from residual carbon present in the soil. Also, little information is available about the nutritional effects and genetic modifications induced by CNTs [34]. At high concentrations, CNTs have been found to have a detrimental effect on plant growth, while at lower levels they exhibit a beneficial effect or no effect at all [34]. A common mechanism explaining the toxicity caused by CNTs is the production of oxidative stress by formation of reactive oxygen species (ROS). The toxicity caused by MWCNTs includes histone modifications and DNA methylation [35]. On exposure to CNTs, plant cells experience damage to cell membrane, loss of mitochondrial dehydrogenase activity and production of ROS [35].

Conclusions

CNTs can be readily absorbed by plants which result in their internal translocation. The CNT-added biofertilizer provides large surface area, high reactivity, compatible pore size and particle morphology which helps in providing nutrients to plants for improving their growth and yields. A positive physiological response is displayed by plants when CNTs are administered at low concentrations. At higher concentrations, usually detrimental effects on plant growth are observed. The effect of CNTs on the surrounding environment also needs to be further investigated before their widespread use in agriculture and plant protection can be recommended.

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