沙漠研究 **19**-1, 129- 132 (2009)
Journal of Arid Land Studies

"Desert Technology IX "
Refereed Paper

Increasing Fertilizer and Pesticide Use Efficiency by Nanotechnology in Desert Afforestation, Arid Agriculture

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Abstract: Low water and fertilizer use efficiency has detrimental effect on arid area agriculture and afforestation. Nanofertlizer application through foliar and earthen pot system has immense potential in overcoming these lacunae. A comparative study of root, stem and fruit growth was conducted on *Emblica officinalis* (Aonla-Chakaia, NA7) with reference to tradition method of fertilizer application and foiliar as well as earthen pot based nanofertlizer application. Result indicates 40% higher growth in terms of carbon content and four times stronger growth in root system.

Keywords: Desert afforestation, Earthen pot system, Fertilizer use efficiency, Nanofertlizer

1. Introduction

Biotechnological innovations in agriculture sciences won't be sufficient to feed the burgeoning population by next decade. At the same time, existing agricultural lands are on decline due to urbanization, industrialization and biofuel production[A]. Areas under organic farming have been also increasing, thereby, reducing productivity by almost half. Traditional methods of agriculture and plantation contribute to rapid losses of applied nutrients and thus, fertilizer use efficiency. This is particularly true with nitrogen. In India, the average fertilizer use efficiency is 12-13% only, which accounts for a loss of Rs. 6.5 billion/yr. Besides, the process of fertilizer application gives rise to unbalanced fertilization. In an experiment on balanced fertilization of K-N ratio (1:0.36), the agronomic efficiency of N increased from 11.5 kg grain (per kg N) to 14.8 kg, and the recovery efficiency increased from 31 to 40%.

Nanotechnology has potential to bring revolution in the field of arid afforestation and agriculture. It facilitates enhanced and elegant properties of molecules that could be developed in material if used at nanoscale. They have intrinsic properties of different kinds, so the majority of the atoms are in the different environment showing different physical, chemical, mechanical, optical properties, which can be exploited for different uses. These nano-structured molecules can change the concept of fertilizers and irrigation methods. Arid area agriculture and desert rehabilitation could be techno-economically feasible.

2. Thermodynamical concept of nanofertilizer

Concept of nanofertilizer is based on the laws of thermodynamics, which sates that entropy of the particular particle is based on randomness. When it is present in emulsion form, nanograde colloids have more suspension compared to ordinary grade fertilizer. Therefore it has more entropy. Entropy is directly proportional to Gibbs free energy. With increase in Gibbs free energy (G) of the colloidal particles its movement would also increase. This enhances the permeability of the particles across the membrane. Hence particles penetrate the cell membrane and enter inside the xylem of the plant. It theoretically explains why the absorption of nanofertilizer is more than that of commercial grade fertilizers in foliar application of fertilizer. Gibbs free energy ($G = H - TS$) can have positive, negative or zero value. Here, H = Enthalpy, S = entropy, T = temperature. If G is negative, the reaction is spontaneous and moves in forward direction. If G is zero, the reaction is at equilibrium. And if G is positive then reaction is non spontaneous. As temperature increases Gibbs free energy decreases (according to the equation). But in normal condition, we do not have control over temperature. Hence, to decrease Gibbs free energy for increasing the reaction rate in forward direction, the other way is to increase entropy of the system. Here we exploit the nature of nanofertilizer whereby entropy is bound to be high. We can find

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out the range of size of nanograde so that to attain negative Gibbbs free energy optimally. In this way, the concept of free energy enhances the rate of penetration of nanofertilizer when their randomness is high inside the tissues of the plant.

3. Materials and Methods

When nano-structured particles of fertilizers are used, it can be called nanofertilizer. The concept of nanofertilizer is similar to that of zeolite used as zeoponic (www.zeoponix.com). Zeoponics increase nutrient retention, reduce environmental nutrient losses and reduce fertilizer requirements by establishing a replenishable and balanced nutrient supply in the plant root zone. Application of urea fertilizer (molecular wt. 60.06 mg, H - 6.71%, C – 20.0%, N – 46.65%, O – 26.64%) at nanoscale, in 10-100 nm size against usual size of 10^{-3} m is one such example.

When urea is applied, it first reacts with soil moisture (water) and forms ammonium carbonate. Ammonium carbonate is highly unstable at neutral pH, which will break into ammonium ion and carbonate ion, at the same time ammonia gas is formed. Ammonia gas escapes to atmosphere, called evaporation loss of nitrogen. The conversion of amide form of urea into ammonical form takes about 4-6 days. Ammonical form of NH_4^+ is consumed by the plant root. The loss of nitrogen is due to two reasons: (1) Draining out of urea much deeper in the soil till it gets converted into ammonical form which is consumed by the root for plant growth and, (2) loss of nutrient in form of ammonia gas to the environment. Presence of nanoscale molecules in urea increases the reaction rate of conversion of urea into ammonium ion. Besides, more surface area speeds up the dissociation rate of ammonium carbonate into ammonium ion and carbonate ion. Nanofertilizer remains available in the emulsion form through out the water layer in water logged condition, and/or earthen pot irrigation system. To block ammonia gas from escaping to environment, a layer of inhibitors or nanoclusters on the surface of the soil (that is water logged) may be used (Giocchini *et al*., 2002). This ammonia will further combine with the carbon dioxide, an output of root respiration process, to ultimately form ammonical form of urea, to be consumed by plant. The nano layer created on the water surface reduces not only the losses of the free water but also help in the recycling of the carbon.

Foliar application of nanofertilizer also increases fertilizer use efficiency. Zeolite-based synthetic substrate, termed zeoponics (nanograde fertilizer), consists of NH_4^+ and K^+. These ions occur in free form which can easily be exchanged. It contains clinoptilolite and a synthetic apatite whose water solution provides essential nutrients through mineral dissolution and ion exchange to the whole plant. This fertilizer should remain in the form of colloidal suspension which readily spreads into plant tissues due to their nanostructured form. The nanostructured fertilizer easily crosses plasma membrane after the spray through the xylem tissues which appear on the surface of the leaf as shown in **Figure 1**. Nanostructured fertilizer is expected to be translocated into the plant. This creates the vegetative growth in plant during the early stage so plant survives even under drought condition. The free NH_4^+ ion could easily be absorbed by the plant.

Emblica officinalis (Aonla-Chakaia, NA7) is selected for plantation due to its proven ability towithstand harshness of arid climate and bad soil conditions. It has several medicinal values. Modern uses include pronounced expectorant, antioxidant, anti cancerous. The effectiveness of nanofertilizer (nano particles of urea, $(NH_2)_2CO$) and nano organic pesticide (nano particles of neem oil in 25 ppm concentration) was used in the field experiments. Two sets of experiments are conducted, (1) fertilizer and pesticide application through conventional surface irrigation and (2) fertilizer and pesticide application through foilar spray and earthen pot.

Oval shaped Earthen pots of 12 -18 lts capacity and 30 cm depth inside the soil were used. Two small holes of 1 cm diameter were made at the bottom of the pot and jute rope, is used to connect them with the root zone of the plant. It supplies fertilizer mixed water in colloidal form to the roots of the plants by capillary action at a depth of 30 cm, the depth where evaporation effect is balanced by gravitational force (Gautam *et al*., 2006). This allows maximum water absorption by the root system. Though, there has been some evaporation from the opening of the earthen pot, it was important to control the temperature of the water during high temperature in summer. The earthen pot having capacity of 15 lts are filled up every week. It took 3-4 days to be completely empty. Plants were stressed for three days in a week.

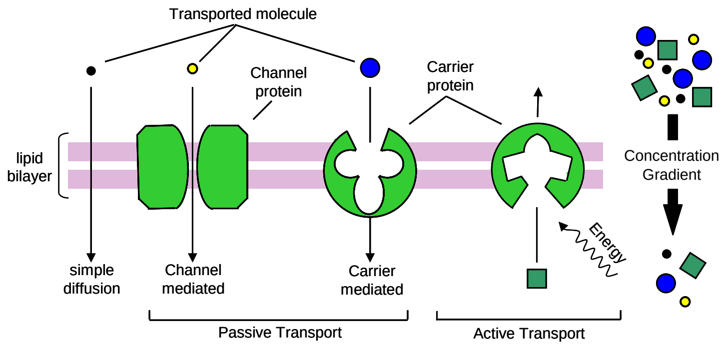

Fig. 1. Foiliar application of nanostructured fertilizer and mechanism.

Table 1. Organic neem pesticide (Azadirachtin) concentration when used with earthen pot system.

Position	Expected	Actual Conc.	Disparity	Overall result	% Content
Top Layer	25 ppm	75 ppm	+200%	3 times (dangerous)	18
Middle Layer	25 ppm	16 ppm	- 36%	1/3 shortfall (poor)	72
Bottom Layer	25 ppm	7 ppm	-75%	3 times shortfall (very poor)	10

4. Results and Discussion

Conventional organic neem pesticide (Azadirachtin) when used through earthen pot system has variable concentration as shown as in **Table 1**. When nanopaticles were used, the concentration remained same (25 ppm) throughout the layer. Similar was the case with nanofertilizers. This indicates fertilizer and pesticide use efficiency increases with water use efficiency due to emulsification.

Figures 2 and **3** show the plant growth after two years when (1) fertilizer and pesticides were used in conventional mode with surface irrigation, and (2) nanofertilizer and naopesticide were used in earthen pot system and foiliar application. The amount of fertilizer used in the later case is half of the former. **Figures 2b** and **3b** show the root development in the two cases. In the former, root development is weak and equally distributed in all directions. In the latter case roots going beneath the earthen pot are much stronger. The perimeter of the strongest root was found 7.1 cm nearly four times the roots of the former. The stem diameter at knot was found to be 17.8 and 20.3 cm respectively, nearly 15% more than the former. Height of the plant was nearly same but branch development was stronger and better in the nanofertilizer application case (**Figs 2a** and **3a**). It indicates deeper penetration of main root system in quest of water seeping to deeper depths due to gravity and sandy soil. However, it has very adverse effect on branch development, necessary for fruiting. While the former has no fruiting in the first year, the later bore fruits.

Fig. 2a. Surface Irrigation and fertilizer application.

Fig. 3a. Foliar and EP based nanofertilizer application.

Fig. 2b. Root development in Surface application.

Fig. 3b. Root development in EP fertilizer application.

Fig. 2c. Knot diameter in fertilizer application.

Fig. 3c. Knot diameter EP fertilizer application.

These preliminary results indicate that the behaviour pattern of fertilizer use efficiency particularly in case of urea at nanoscale (10-100 nm size against usual size of 10-3 m). If the total carbon content of the plant is considered, the fertilizer use efficiency is 40% more in the later case even in two year period.

5. Conclusions

Substantial growth in fertilizer use efficiency can be achieved by nanoscale fertilizers in the wake of global warming. Other advantages include, increase in chances of plant survival, higher stem yield at lower input price. Given the demand and economic importance of *Emblica officinalis*, the methodology developed has immense potential. It uses environment friendly earthen pot, which uses local materials and also generates employment in remote areas. Besides, the rapid growth of *Emblica officinalis* in such an hostile environment provides hope for the growth of other plants too.

Annotation

A) Mac Margolis (2007): Untold Harvest, *Newsweek*, pp 54-55, April 16/April 23.
B) http://www.zeoponix.com/zeolite.htm

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