POLICY PAPER

63

Nanotechnology in Agriculture: Scope and Current Relevance

NAAS

NATIONAL ACADEMY OF AGRICULTURAL SCIENCES, NEW DELHI

December 2013

Nanotechnology in Agriculture: Scope and Current Relevance

NATIONAL ACADEMY OF AGRICULTURAL SCIENCES, NEW DELHI

December 2013

CONVENER : Dr J.C. Tarafdar, ICAR National Fellow, Central Arid Zone Research Institute, Jodhpur

EDITORS : Dr C. Devakumar
: Dr P.K. Chhonkar

REVIEWERS : Dr S. Kundu, Dr S.S. Mukhopadhyay, Dr S.K. Sanyal and Dr K.V.B.R. Tilak

CITATION : NAAS 2013. Nanotechnology in Agriculture: Scope and Current Relevance. Policy Paper No. 63, National Academy of Agricultural Sciences, New Delhi: 20 p.

Published by Mr H.C. Pathak, Executive Secretary on behalf of
NATIONAL ACADEMY OF AGRICULTURAL SCIENCES
NASC, Dev Prakash Shastry Marg, New Delhi - 110 012
Tel: (011) 25846051-52; Fax: (011) 25846054
Email: naas@vsnl.com; Web site: http://www.naasindia.org

Preface

Nanotechnology, which deals with the matter at nanoscale (1-100 nm), is commonly referred to as a generic technology that offers better-built, safer, long-lasting, cost-effective and smart products that will find wide applications in household, communications, medicine, agriculture and food industry, amongst others. Nanotechnology-based products and its applications in agriculture include nano-fertilizers, nano-herbicides, nano-pesticides, recalcitrant contaminants from water, nano-scale carriers, nanosensors, veterinary care, fisheries and aquaculture, detection of nutrient deficiencies, preservation, photocatalysis, nanobarcode, quantum dots etc. This fast growing technology is already having a significant commercial impact, which will certainly increase in the future. While nanotechnologies offer many opportunities for innovation, the use of nanomaterials in food and agriculture has also raised a number of safety, environmental, ethical, policy and regulatory issues.

With the above backdrop, the National Academy of Agricultural Sciences (NAAS), involving leading nanotechnologists, organised a Brainstorming Session entitled 'Nanotechnology in Agriculture : Scope and its Current Relevance' on April 23, 2013 to discuss issues related to the potential effects and impact on human health and the environment that might arise from exposure to nanosized materials. I am confident that this Policy Paper emanating from the Session would help the Government of India and other relevant bodies towards making strategic plans for investment in nanoscience research and technology development with special reference to agricultural transformation.

The Academy appreciates the efforts of Dr. J.C. Tarafdar and his team in convening the brainstorming event. Grateful thanks are due to Resource Persons, Reviewers and Editors of the policy paper.

(R.B. Singh)
President, NAAS

Nanotechnology in Agriculture: Scope and Current Relevance

1.0 INTRODUCTION

Agricultural scientists are facing a wide spectrum of challenges such as stagnation in crop yields, low nutrient use efficiency, declining soil organic matter, multi-nutrient deficiencies, climate change, shrinking arable land and water availability and shortage of labour besides exodus of people from farming. In spite of immense constraints faced, we need to attain a sustainable growth in agriculture at the rate of 4% to meet the food security challenges. To address these problems, there is a need to explore one of the frontier technologies such as 'Nanotechnology' to precisely detect and deliver the correct quantity of nutrients and pesticides that promote productivity while ensuring environmental safety and higher use efficiency. The nanotechnology can be exploited in the value chain of entire agriculture production system (Subramanian and Tarafdar, 2011). Nanotechnology is emerging as the sixth revolutionary technology in the current era after the Industrial Revolution of Mid 1700s, Nuclear Energy Revolution of the 1940s, The Green Revolution of 1960s, Information Technology Revolution of 1980s and Biotechnology Revolution of the 1990s. It is now emerging and fast growing field of science which is being exploited over a wide range of disciplines such as physics, chemistry, biology, material science, electronics, medicine, energy, environment and health sectors.

Nantechnology deals with the matter at nanoscale (1-100 nm) dimensions. These materials when reduced to the nanoscale show some properties which are different from what they exhibit on a macro scale, enabling unique applications. Nanoscience has brought revolution in different fields by helping develop processes and products that are hardly possible to evolve through conventional methods. The nanotechnology-aided applications have the potential to change agricultural production by allowing better management and conservation of inputs of plant and animal production. A survey by Salamanca–Buentella *et al.* (2005) predicted several nanotechnology applications for agricultural production for developing countries within next 10 years. These included - (i) Nanoforms zeolites for slow release and efficient dosage of water and fertilizers for plants; drugs for livestock; nanocapsules and herbicide delivery (ii) Nanosensors for soil quality and for plant health monitoring; nanosensors for pests detection (iii) Nanomagnets for removal of soil contaminants and (iv) Nano-particles for new pesticides, insecticides, and insect repellents.

The recent statistics suggest that about 90% of the nano-based patents and products have come from just seven countries, namely, China, Germany, France, Japan, Switzerland, South Korea and USA while India's investments and progress is far from satisfactory. However, to take advantage of the fascinating field of nano-science, the Government of India has invested Rs. 1000 crore through the Nano Mission Project during 11th Five Year Plan and the investment is likely to be several folds higher during the 12th Five Year Plan period (Box 1).

Box 1. Major Highlights of the Nano Mission, 12th Five Year Plan

Capacity-building in this upcoming area of research is of utmost importance for the Nano Mission so that India emerges as a global knowledge-hub in this field also. For this, research on fundamental aspects on Nano Science and training of large number of manpower are receiving prime attention. The Nano Mission is also making efforts towards development of products and processes for national development, especially in areas of national relevance like safe drinking water, materials development, drug delivery, etc. For this, it is forging linkages between educational and research institutions and industry and promoting Public-Private-Partnership. The Nano Mission is also synergizing the efforts being made by various agencies towards promoting Nano Science and Technology. International collaborations are also being entered into, wherever required. Major activities of the Nano Mission include: Setting up a dedicated Institute of Nano Science & Technology, Post Graduate Programmes (M.Sc/M.Tech.) in 16 Institutions/ Universities across the country, Funding of around 235 individual scientist-centric research projects on fundamental scientific aspects of Nano scale systems, and Laying down a Regulatory Framework for Nanotechnology in India.

Source: Planning Commission, 2011
(http://planningcommission.gov.in/aboutus/committee/wrkgrp12/sandt/wg_dst2905.pdf)

The Indian Council of Agricultural Research (ICAR) has opened up an exclusive platform to target Nanotechnology Applications in Agriculture. The ICAR – Nanotechnology Platform encompasses major themes such as synthesis of nano-particles for agricultural use, quick diagnostic kits for early detection of pests and diseases, nano-pheromones for effective pest control, nano agri-inputs for enhanced use efficiencies, precision water management, stabilization of organic matter in soil, nano food systems and bio safety besides establishing the policy frame work. Green-synthesis and microbial synthesis of nanomaterials for their agricultural use may be very important as they are naturally encapsulated with mother protein, therefore, more stable and safer to biological system. At present in India research is mainly concentrated on nano particle synthesis, smart release of nutrients from nano-fertilizers, nano-induced polysaccharide powder for moisture retention/soil aggregation and C build up, regulated release of active ingredients from nano-encapsulated herbicides, nano-seed invigoration, and slow and steady release of pesticides, nano-film for extended shelf-life of perishables and nano-remediation of soil and aquatic pollutants. These are cutting-edge researchable areas which are expected to expand in the years to come. However, if the nanoproducts and the processes for creating them are not managed judiciously, there could be serious health and environmental risks.

With the above backdrop, the National Academy of Agricultural Sciences (NAAS), involving leading nanotechnologists, organised a Brainstorming Session entitled 'Nanotechnology in Agriculture : Scope and Current Relevance' on April 23, 2013 to discuss issues related to the potential effects and impact on human health and the environment that might arise from exposure to nanosized materials. This document summarizes the status of the use of the technology and the policy options and actions for utilizing it in India.

2.0 APPLICATIONS

2.1 Application of Nanotechnology in Seed Science

Seed is most important input determining productivity of any crop. Conventionally, seeds are tested for germination and distributed to farmers for sowing. In spite of the fact that seed testing is done in well equipped laboratories, it is hardly reproduced in the field due to the inadequate moisture under rainfed conditions. In India, more than 60% of the net area sown is rainfed; hence, it is quite appropriate to develop technologies for rainfed agriculture. A group of research workers is currently working on metal oxide nano-particles and carbon nanotube to improve the germination of rainfed crops. Khodakovskaya *et al.* (2009) have reported the use of carbon nano-tube for improving the germination of tomato seeds through better permeation of moisture. Their data show that carbon nanotubes (CNTs) serve as new pores for water permeation by penetration of seed coat and act as a passage to channelize the water from the substrate into the seeds. These processes facilitate germination which can be exploited in rainfed agricultural system.

2.2 Nano-fertilizers for balanced crop nutrition

In India, fertilizers, alongwith quality seed and irrigation, are mainly responsible for enhanced food grain production (55 mt) in 1960s to (254 mt) in 2011 coinciding with the spectacular increase in fertilizer consumptions from 0.5 mt to 23 mt, respectively.

It has been conclusively demonstrated that fertilizer contributes to the tune of 35-40% of the productivity of any crop. Considering its importance, the Government of India is heavily subsidising the cost of fertilizers particularly urea. This has resulted in imbalanced fertilization and occurrence in some areas, nitrate pollution of ground waters due to excessive nitrogen application. In the past few decades, use efficiencies of N, P and K fertilizers have remained constant as 30-35%, 18-20% and 35-40%, respectively, leaving a major portion of added fertilizers to accumulate in the soil or enter into aquatic system causing eutrophication. In order to address issues of low fertilizer use efficiency, imbalanced fertilization, multi-nutrient deficiencies and decline of soil organic matter, it is important to evolve a nano-based fertilizer formulation with multiple functions.

Nano-fertilizer technology is very innovative but scantily reported in the literature. However, some of the reports and patents strongly suggest that there is a vast scope for the formulation of nano-fertilizers. Significant increase in yields have been observed due to foliar application of nano particles as fertilizer (Tarafdar, 2012; Tarafdar *et al.* 2012a). It was shown that 640 mg ha^{-1} foliar application (40 ppm concentration) of nanophosphorus gave 80 kg ha^{-1} P equivalent yield of clusterbean and pearl millet under arid environment. Currently, research is underway to develop nano-composites to supply all the required essential nutrients in suitable proportion through smart delivery system. Preliminary results suggest that balanced fertilization may be achieved through nanotechnology (Tarafdar *et al.* 2012b).

Indeed the metabolic assimilation within the plant biomass of the metals, e.g., micronutrients, applied as Nano-formulations through soil-borne and foliar application or otherwise needs to be ascertained. Further, the Nano-composites being contemplated to supply all the nutrients in right proportions through the "Smart" delivery systems also needs to be examined closely. Currently, the nitrogen use efficiency is low due to the loss of 50-70% of the nitrogen supplied in conventional fertilizers. New nutrient delivery systems that exploit the porous nanoscale parts of plants could reduce nitrogen loss by increasing plant uptake. Fertilizers encapsulated in nanoparticles will increase the uptake of nutrients (Tarafdar *et al.* 2012c). In the next generation of nanofertilizers, the release of the nutrients can be triggered by an environmental condition or simply released at desired specific time.

2.3 Nano-herbicide for effective weed control

Weeds are menace in agriculture. Since two-third of Indian agriculture is rainfed farming where usage of herbicide is very limited, weeds have the potential to jeopardize the total harvest in the delicate agro-ecosystems. Herbicides available in the market are designed to control or kill the above ground part of the weed plants. None of the herbicides inhibits activity of viable belowground plant parts like rhizomes or tubers, which act as a source for new weeds in the ensuing season. Soils infested with weeds and weed seeds are likely to produce lower yields than soils where weeds are controlled. Improvments in the efficacy of herbicides through the use of nanotechnology could result in greater production of crops. The encapsulated nano-herbicides are relevant, keeping in view the need to design and produce a nano-herbicide that is protected under natural environment and acts only when there is a spell of rainfall, which truly mimics the rainfed system.

Developing a target specific herbicide molecule encapsulated with nanoparticle is aimed for specific receptor in the roots of target weeds, which enter into roots system and translocated to parts that inhibit glycolysis of food reserve in the root system. This will make the specific weed plant to starve for food and gets killed (Chinnamuthu and Kokiladevi, 2007). Adjuvants for herbicide application are currently available that claim to include nanomaterials. One nanosurfactant based on soybean micelles has been reported to make glyphosate-resistant crops susceptible to glyphosate when it is applied with the 'nanotechnology-derived surfactant'.

2.4 Nano-pesticide

Persistence of pesticides in the initial stage of crop growth helps in bringing down the pest population below the economic threshold level and to have an effective control for a longer period. Hence, the use of active ingredients in the applied surface remains one of the most cost-effective and versatile means of controlling insect pests. In order to protect the active ingredient from the adverse environmental conditions and to promote persistence, a nanotechnology approach, namely "nano-encapsulation" can be used to improve the insecticidal value. Nano-encapsulation comprises nano-sized particles of the active ingredients being sealed by a thin-walled sac or shell (protective coating). Recently, several research papers have been published on the encapsulation of insecticides. Nano-encapsulation of insecticides, fungicides or nematicides will help in producing a formulation which offers effective control of pests while preventing accumulation of residues in soil. In order to protect the active ingredient from degradation and to increase persistence, a nanotechnology approach of "controlled release of the active ingredient" may be used to improve effectiveness of the formulation that may greatly decrease amount of pesticide input and associated environmental hazards. Nano-pesticides will reduce the rate of application because the quantity of product actually being effective is at least 10-15 times smaller than that applied with classical formulations, hence a much smaller than the normal amount could be required to have much better and prolonged management.

Several pesticide manufacturers are developing pesticides encapsulated in nanoparticles (OECD and Allianz, 2008). These pesticides may be time released or released upon the occurrence of an environmental trigger (for example, temperature, humidity, light). It is unclear whether these pesticide products will be commercially available in the short-term.

Plant diseases are major factors limiting crop yields. The problem with the disease management lies with the detection of the exact stage of prevention. Most of the time appropriate plant protection chemicals are applied to the crop as a precautionary measure leading to avoidable environmental hazards, or else applications are made after the appearance of the disease symptoms, thereby causing some amount of crop losses. Among the different diseases, the viral diseases are the most difficult to control, as one has to stop the spread of the disease by the vectors. But once it starts showing its symptoms, pesticide application would not be of much use. Therefore, detection of the exact stage such as stage of viral DNA replication or the production of initial viral protein is the key to the success of control of viral diseases. Nano-based viral diagnostics, including multiplexed diagnostics kits development, have taken momentum in order to detect the exact strain of virus and the stage of application of some therapeutic to stop the disease. Detection and utilization of biomarkers, that accurately indicate disease stages, is also an emerging area of research in bio-Nanotechnology. Measuring differential protein production in both healthy and diseased states leads to the identification of the development of several proteins during the infection cycle.

Clay nanotubes (halloysite) have been developed as carriers of pesticides at low cost, for extended release and better contact with plants, and they will reduce the amount of pesticides by 70-80%, thereby reducing the cost of pesticide with minimum impact on water streams.

2.5 Nanotechnology in Water Management

Nanotechology, offers the potential of novel nanomaterials for the treatment of surface water, groundwater and wastewater contaminated by toxic metal ions, organic and inorganic solutes and microorganisms. Due to their unique activity towards recalcitrant contaminants many nanomaterials are under research and development for use for water purification.

To maintain public health, pathogens in water need to be identified rapidly and reliably. Unfortunately, traditional laboratory tests are time consuming. Faster methods involving enzymes, immunological or genetic tests are under development. Water filtration may be improved with the use of nanofiber membranes and the use of nanobiocides, which appear promisingly effective. Biofilms contaminating potable water are mats of bacteria wrapped in natural polymers which are difficult to treat with antimicrobials or other chemicals. They can be cleaned up only mechanically, which cost substantial down-time and labour. Work is in progress to develop enzyme treatments that may be able to break down such biofilms.

2.6 Nano-scale carriers

Nanoscale carriers can be utilized for the efficient delivery of fertilizers, pesticides, herbicides, plant growth regulators, etc. The mechanisms involved in the efficient delivery, better storage and controlled release include: encapsulation and entrapment, polymers and dendrimers, surface ionic and weak bond attachments among others. These help to improve stability against degradation in the environment and ultimately reduce the amount to be applied, which reduces chemical runoff and alleviates environmental problems. These carriers can be designed in such a way that they can anchor plant roots to the surrounding soil constituents and organic matter. This can only be possible if we unrevel the molecular and conformational mechanisms between the nanoscale delivery and targeted structures, and soil fractions. Such advances as and when they happen will help in slowing the uptake of active ingredients, thereby reducing the amount of inputs to be used and also the waste produced.

2.7 Biosensors to detect nutrients and contaminants

Protection of the soil health and the environment requires the rapid, sensitive detection of pollutants and pathogens with molecular precision. Soil fertility evaluation is being carried out for the past sixty years with the same set of protocols which may be obsolete for the current production systems and in the context of precision farming approaches. Accurate sensors are needed for *in situ* detection, as miniaturized portable devices, and as remote sensors, for the real-time monitoring of large areas in the field.

These instruments are able to reduce the time required for lengthy microbial testing and immunoassays. Application of these instruments include detection of contaminants in different bodies such as water supplies, raw food materials and food products. Enzymes can act as a sensing element as these are very specific in attachment to certain biomolecules. Electronic nose (E-nose) is used to identify different types of odors; it uses a pattern of response across an array of gas sensors. It can identify the odorant, estimate the concentration of the odorant and find characteristic properties of the odor in the same way as might be perceived by the human nose. It mainly consists of gas sensors which are composed of nanoparticles e.g. ZnO nanowires. Their resistance changes with the passage of a certain gas and generates a change in electrical signal that forms the fingerprint pattern for gas detection.

Biosensors provide high performance capabilities for use in detecting contaminants in food or environmental media. They offer high specificity and sensitivity, rapid response, user-friendly operation, and compact size at a low cost (Amine *et al.*, 2006). While the direct enzyme inhibition sensors currently lack the analytical ability to discriminate between multiple toxic substances in a sample (such as simultaneous presence of heavy metal and pesticide), they may prove useful as a screening tool to determine when a sample contains one or more contaminants. These methods are amenable to deployment in single-use test strips (making them useful to those in the field).

According to Hu *et al.* (2010), detection of multiple residues of organophosphorus pesticides has been accomplished using a nanomagnetic particle in an enzyme-linked immunosorbent assay (ELISA) test. The authors suggest that ELISA is more cost-effective than analytical tests requiring expensive laboratory equipment with high levels of skill.

2.8 Agricultural Engineering Issues

Nanotechnology has many applications in the field of agricultural machinery. These cover: application in machine structure and agricultural tools to increase their resistance against wear and corrosion and ultraviolet rays; producing strong mechanical components with use of Nano-coating and use of bio-sensors in smart machines for mechanical-chemical weed control; production of Nano-cover for bearings to reduce friction. The use of Nanotechnology in production of alternative fuels and reduction of environmental pollution are also worth mentioning.

2.9 Application of Nanotechnology in Animal Sciences

Nanotechnology has the ability to provide appropriate solutions for addressing the issues of food items, veterinary care and prescription medicines as well as vaccines for domesticated animals. Taking certain medications such as antibiotics, vaccines, and probiotics, would be effective in treating the infections, nutrition and metabolic disorders, when used at the nano level. Medicines used at the nano level have multilateral properties to remove biological barriers for increased efficiency of the applied medicine. Appropriate timing for the release of drug and self-regulatory capabilities are the main advantages of the use of nanotechnology in the application of drugs.

The C-60 carbon particle (bucky ball) is spherical molecule having nearly 1 nm diameter. It is non-toxic to the live cells and biocompatible in nature. It can be used as a carrier to deliver the water soluble peptides and drugs. The nanotechnology can help to understand certain drug behaviour in an animal body. The nano particles can penetrate the skin through minor abrasions; these are reported to be used as sensor to detect the altered cell behaviour. The dendrimers are synthetic three dimensional macromolecules having a core particle surrounded by branches like a tree. They can be conjugated with the target molecule like drug as they are biocompatible and are easily cleared from blood through the kidney. It was observed that *in vivo* delivery of dendrimer-methotrexate reduce the tumour size ten times more than the free methotrexate (Hong *et al.*, 2007).

The nano-magnets can be used as drug delivery system specially to treat the cancerous growth without any harm to the surrounding tissues. Different types of proteins like albumin, gelatin, gliadin and legumin can be used to prepare nanoparticle-based drug delivery system. Inert nanobeads were used to neutralize the antigen causing osteoarthritis in racing horses. Use of nano based antibiotics in treatment of animal diseases requires less amounts of antibiotics leaving less antibiotic residues. Nanoparticle based chromium supplementation has beneficial effects on growth performance and body composition and it increases tissue chromium concentration in the muscles. Iron deficiency is a common problem in animals, especially during the early stage of life, gestation and parasitic infestation due to less bioavailability. The bioavailability can be increased with the supplementation of ferric phospholic nano-particles.

Nanotechnology is used to produce the chicken/ goat meat in the laboratory in large quantities maintaining the same nutritive value, taste, texture without any hazard (*vegetarian meat*). It can be eaten by the vegetarians also. It may solve the food scarcity problem, thereby eradicating the hunger. Use of nanotechnology in *designer egg* production is well-known. It can produce the eggs with low cholesterol, less yolk content, more nutrients, and desired antibodies. In addition, nano-based sensors can help in early detection of egg-borne pathogens (Verma *et al.*, 2012).

2.10 Nano technology application in fisheries and aquaculture

Nanotechnology has tremendous potential to revolutionize fisheries and aquaculture sector. Nanotechnology tools like nano-materials, nano-sensor, DNA nano-vaccines, gene delivery and smart drug delivery have the potential of solving many puzzles related to fisheries nutrition and health production, reproduction, prevention and treatment of disease. Nanotechnology will help fish processing industry for producing quality products by detecting bacteria in packaging, producing strong flavour, colour quality and safety.

3.0 SMART DELIVERY SYSTEMS

Nanoscale devices are envisioned that would have the capability to detect and treat diseases, nutrient deficiencies or any other maladies in crops long before symptoms were visually exhibited. “Smart Delivery Systems” for agriculture can possess timely controlled, spatially targeted, self-regulated, remotely regulated, pre-programmed, or multi-functional characteristics to avoid biological barriers to successful targeting. Smart delivery systems can monitor the effects of delivery of nutrients or bioactive molecules or any pesticide molecules. This is widely used in health sciences wherein nanoparticles are exploited to deliver required quantities of medicine to the place of need in human system. In the smart delivery system, a small sealed package carries the drug which opens up only when the desirable location or infection site of the human or animal system is reached. This would allow judicious use of antibiotics than otherwise would be possible.

3.1 Nanodevices for Identity Preservation (IP) and Tracking

One of the major constraints in Indian agriculture is the quality maintenance of agricultural produce. Proper monitoring of production system through nanotechnology will be appropriate to promote quality and make a clear distinction with organic products. Identity Preservation (IP) is a system that creates increased value by providing customers with information about practices and activities used to produce a particular crop or other agricultural products. Certifying inspectors can take advantage of IP as a better way of recording, verifying, and certifying agricultural practices. Through IP, it is possible to provide stakeholders and consumers with access to information, records and supplier protocols. Quality assurance of agricultural products safety and security could be significantly improved through IP at the nano-scale. Nano-scale IP holds the possibility of continuous tracking and recording of the history which a particular agricultural product experiences. The nano-scale monitors may be linked to the recording and the tracking devices to improve identity preservation of food and agricultural products. The IP system is highly useful to discriminate organic versus conventional agricultural products.

3.2 Nanolignocellulosic materials

Recently, nanosized lignocellulosic materials have been obtained from crops and trees which had opened up a new market for innovative and value-added nano-sized materials and products, e.g. nano-sized cellulosic crystals have been used as lightweight reinforcement in polymeric matrix (Mathew *et al.*, 2009). These can be applied in food and other packaging, construction, and transportation vehicle body structures. Cellulosic nano-whisker production technology from wheat straw has been developed by the Michigan Biotechnology Incorporate (MBI) International, and is expected to make biocomposites that could substitute for fiberglass and plastics in many applications, including automative parts (Liestritz, 2007). For the commercialization of this technology, North Dakota State University (NDSU), USA is currently engaged in a project.

3.3 Photocatalysis

One of the processes using nanoparticles is photocatalysis. The mechanism of this reaction is that when nanoparticles of specific compounds are subjected to UV light, the electrons in the outermost shell (valence electrons) are excited resulting in the formation of electron hole pairs, i.e. negative electrons and positive holes. Analogy with n- and p-type semiconductors, i.e., the Group IV elements, e.g. Germenium of the Periodic Table, dopted with, respectively, minute quantities of the Group V and Group III impurities, is worth noting. Due to their large surface-to-volume ratio, these have very efficient rates of degradation and disinfection. As the size of the particles decrease, surface atoms are increased, which results in tremendous increase in chemical reactivity and other physico-chemical properties related to some specific conditions such as photocatalysis, photoluminescence, etc. So this process can be used for the decomposition of many toxic compounds such as pesticides, which take a long time to degrade under normal conditions. Nanoparticles can be used for the bioremediation of resistant or slowly degradable compounds like pesticides.

The removal of toxins from wastewater is an emerging issue due to its effects on living organisms. Many strategies have been applied for wastewater treatment with little success. Photocatalysis can be used for purification, decontamination and deodorization of air. It has been found that semiconductor sensitized photosynthetic and photocatalytic processes can be used for the removal of organics, destruction of cancer cells, bacteria and viruses. Application of photocatalytic degradation has gained popularity in the area of wastewater treatment.

3.4 Nanobarcode technology

In our daily life, identification tags have been applied in wholesale agriculture and livestock products. Due to their small size, nanoparticles have been applied in many fields ranging from advanced biotechnology to agricultural encoding. Nanobarcodes (> 1 million) have been applied in multiplexed bioassays and general encoding because of their possibility of formation of a large number of combinations that render them attractive for this purpose. The UV lamp and optical microscope are used for the identification of micrometer-sized glass barcodes which are formed by doping with rare earth containing a specific type of pattern of different fluorescent materials. The particles to be utilized in nanobarcodes should be easily encodeable, machine-readable, durable, sub-micronsized taggant particles. For the manufacture of these nanobarcode particles, the process is semi-automated and highly scalable, involving the electro plating of inert metals (gold, silver, etc.) into templates defining particle diameter, and then the resulting striped nanorods from the templates are released.

Nanobarcodes have been used as ID tags for multiplexed analysis of gene expression and intracellular histopathology. In the near future, more effective identification and utilization of plant gene trait resources is expected to introduce rapid and cost effective capability through advances in nanotechnology-based gene sequencing. Nanobarcodes serve as uniquely identifiable nanoscale tags and have been applied for non-biological applications such as for authentication or tracking in agricultural food and husbandry products. Such nanobarcode technology will enable one to develop new auto-ID technologies for the tagging of items previously not practical to tag with conventional barcodes. With the enhanced importance of traceability in food trade, such technologies will be helpful in promoting biosafe international food trade.

3.5 Quantum dots (QDs) for staining bacteria

Bacteria, the most primitive life forms present almost everywhere, are useful as well as harmful for life. There are numerous bacteria which are responsible for many diseases in human like tetanus, typhoid fever, diptheria, syphilis, cholera, food-borne illness, leprosy and tuberculosis caused by different species. As a remedial process, we need to detect bacteria and for this, dye staining method is used. To stain bacteria, the most commonly used biolabels are organic dyes, but these are expensive and their fluorescence degrades with time. Fluorescent labeling by quantum dots (QDs) with bio-recognition molecules has been discovered through the recent developments in the field of luminescent nanocrystals. QDs are better than conventional organic fluorophores (dyes) due to their more efficient luminescence compared to the organic dyes, narrow emission spectra, excellent photostability, symmetry and tunability according to the particles sizes and material composition. By a single excitation light source, they can be excited to all colors of the QDs due to their broad absorption spectra. Bio-labeled *Bacillus* bacteria with nanoparticle consisting of ZnS and Mn^{2+} capped with bio compatible ‘chitosan’ gave an organ glow when viewed under a fluorescence microscope. For the detection of *E. coli* O157 : H7, QDs were used as a fluorescence marker coupled with immune magnetic separation. For this purpose, magnetic beads were coated with anti-*E. coli* O157 antibodies to selectively attach target bacteria, and biotin-conjugated anti-*E. coli* antibodies to form sandwich immune complexes. QDs were labeled with the immune complexes via biotin-streptavidin conjugation after magnetic separation.

3.6 Nanobiotechnology

Nanobiotechnology has the potential to increase the efficiency and quality of agricultural production and food storage, to enhance the safety of food supplies for the protection of consumers and producers and to introduce new functionality (value-added products) for food, fiber and agricultural commodities. Nanobiotechnology will pave the ways for new researchable areas and applications such as DNA chip, protein identification and manipulation, novel nucleic acid engineering based films, smart delivery of DNA using gold nanoparticles. Biological tests measuring the presence or activity of selected substances become quicker, more sensitive and more flexible when nano-particles are put to work as tags or labels. Magnetic nanoparticles, bound to suitable antibody, are used to label specific molecules, structures or microorganisms.

3.7 Nano-food industry

During the last three years, food industries have witnessed that the nanotechnology has been really integrated in a number of food and food packaging products. There are now over 300 nanofood products available on the market worldwide. These exciting achievements have encouraged a large increase of R & D investments in nanofood. Today, the Nanotechnology is no longer an empty buzzword, but an indispensable reality in the food industry. The impact of nanotechnology is huge, ranging from basic food to food processing, from nutrition delivery to intelligent packaging. It is estimated that the nanotechnology and nano-bio-info convergence will influence over 40% of the food industries up to 2015. There is a strong need to develop nanofood through nano-engineering of food ingredients. Under this, texture, taste, flavour and color of food ingredients can be modified using nanoengineering without losing their nutritional value or with improved nutritional quality. Nanotechnology can extend the shelf-life of perishables like fruits, vegetables, and flowers during transportation, thus preventing the post-harvest losses.

3.8 Nanoparticles for filtration

The NRC report (2008) on emerging technologies that will benefit farmers in Africa and Asia lists several nanomaterials that are believed to be economical and effective for water purification. Nano-enabled water treatment techniques rely on membranes and filters made of carbon nanotubes, nanoporous ceramics, and magnetic nanoparticles rather than the use of chemicals and ultraviolet light used in conventional water treatment (Hillie and Hlophe, 2007). Carbon nanotube filters can be used to remove impurities from drinking water. A fused carbon nanotube mesh that can filter out water-borne pathogens, lead, uranium, and arsenic has been suggested as a useful nanotechnology by the NRC report. The NRC report also discusses the application of the NanoCeram filter, which uses a positively charged filter to trap negatively charged bacteria and viruses. This filtering device removes endotoxins, DNA, viruses, and micron-sized particles. A simple handheld magnet can be used to remove the nanocrystals and the arsenic from water. Such a treatment could be used as a point-of-use water filtration process. However, the problem remains as how to dispose of the enriched product generated during the filtration process in an eco-friendly manner.

3.9 Wireless nanosensors for precision agriculture

Crop growth and field conditions like moisture level, soil fertility, temperature, crop nutrient status, insects, plant diseases, weeds, etc. can be monitored through advancement in nanotechnology. Such real-time monitoring is done by employing networks of wireless nano-sensors across the cultivated fields, providing essential data for agronomic processes like optimal time of planting and harvesting of the crops. It is also helpful for monitoring the time and amount of water application, fertilizers, pesticides, herbicides and other treatments. This has moved precision agriculture to a much higher level of control, for instance, in water usage, leading eventually to conservation of water. More precise water delivery systems are likely to be developed in the near future. The factors critical for such development include water storage, *in situ* water holding capacity, water distribution near roots, water absorption efficiency of plants, encapsulated water released on demand, and interaction with field intelligence through nano-sensor systems.

4.0 HEALTH & ENVIRONMENTAL CONCERNS

Researchers noted that rats breathing in Nano particles generally have those particles settle in the brain and lungs, which led to significant increases in biomarkers for inflammation and stress response and that Nano-particles include induce skin aging through oxidative stress in hairless mice. Extremely small fibres, so called Nano-fibres, can be as harmful for the lung as asbestos is (*http://www.bbc.co.uk/news/health-193551960*, 2012-08-24). The Royal Society report identified a risk of Nano-particles or Nano-tubes being released during disposal, destruction and recycling, and recommended that "manufacturers of products that fall under extended producer's responsibility regimes such as end-of-life regulations to publish procedures outlining how these materials will be manage to minimize possible human and environmental exposure". Reflecting the challenges for ensuring responsible life cycle regulation, the Institute for Food and Agricultural Standards (*http://www.msu.edu/~ifas/*) has proposed that standards for Nanotechnology research and development be integrated across consumer, worker and environmental standards. They also propose that the NGOs and other citizen groups play a meaningful role in the development of these standards.

The ultra-small sizes that make the nanoparticles of immense usefulness, unfortunately the same characteristic also causes several adverse effects and may represent significant hazards to environment, animals, human beings and plants when used non-judiciously. The possible hazards are mentioned hereunder:

- Nanoparticles as pesticides, fertilizers or in other formulations, when air-borne, may deposit on above ground parts of plants. They may plug stomata and create a fine physical and toxic barrier layer on stigma preventing pollen tube penetration. They may also enter the vascular tissue and impair translocation of water, minerals and photosynthate.

- Animals may inhale nanoparticles resulting into various ill effects and disorders. The particles may enter the bloodstream.

- Nano-pesticides may reduce environmental contamination through the reduction in pesticide application rates, but they may also create new kinds of contamination of soils and waterways due to enhanced transport, longer persistence and higher toxicity.

- Air-borne nanoparticles present some specific hazards for human health, they may enter the body through the respiratory system. Due to the entry of nanoparticles into lungs and blood stream, there is possibility of inflammation, protein fibrillation and induction of genotoxicity.

Because of these risks, the use of nanotechnology in fertilizer and pesticide formulations has to be addressed very cautiously, and this warrants mandatory need to critically analyse and examine the risks involved with the nano-formulations.

5.0 WAY FORWARD: POLICY OPTIONS AND ACTIONS

Nanotechnology has emerged as a cutting edge technology with profound realized and potential outcomes and impacts. It is a powerful tool for food and nutritional security, management of abiotic and biotic stresses, enhanced input use efficiency, elevated yield potential and superior quality traits. However, the process and products if not handled properly, may pose human health and environmental risks. Hence, strategic research and policy options and actions, as informed by rigorous science, are needed to judiciously develop this new emerging technology to be used in agriculture for congruent enhanced productivity, profitability, social equity, biosafety and environmental sustainability.

5.1 Strategic Research

- Strengthen efficacious biological synthesis (green synthesis) of nanoparticles of suitable size and shape.

- Deepen understanding on mycorrhizal fungi and root endophytes which produce a large amount of unknown and uncharacterized nanoparticles that are responsible for plant productivity, as also on the transport of nanoparticles from soil solution to plants and interactions between plants and nanoparticles.
- Streamline the use of Nano-embedded symbiotic fungi and their application on plants of economic importance like sugarcane, pulses, oilseeds and those of medicinal value, and explore the opportunities in tea and plantation crops, spices, and tropical fruits.
- Analyse non-target effects of nanoparticles/nano-formulations/nano-gels on the natural enemies and on the population of soil-borne beneficial micro-flora, various biological control systems such as NPV formulations, *Bt* formulations, *Trichoderma* formulations and EPN formulations need to be studied. Also analyse the side effects of nanoparticles on soil microbial ecology, especially microbial structure and population dynamics.
- Develop suitable protocol of seed coating with micronutrient nano-particles for producing customized seed for micronutrient deficient areas of the country, and develop Nano-sensor based soil, water and pesticide testing tools.
- Work out the economics of the use of nanotechnology based on statistically sound pilot trials, participatory demonstrations and field trials. And, scientifically assess public perception, nano-ethics aspects like nano semantics, nano-praxis and nano-pragmatism, and priority niche areas viz. organics, for application of Nano-technology.

5.2 Policy Options and Actions

5.2.1 Ensure human and environmental health security

- Identify, upgrade and create (if needed) institutions with relevant expertise and facilities and accredit and network them for enhancing their efficiency in biosafety evaluation of nanoparticles. Following the Food Safety and Standards Authority of India (FSSAI) and FAO / WHO standards, formulate clear guidelines regarding the parameters and methodology of monitoring and evaluation.
- Evaluate food and environmental safety of specific nano food/products before their commercial release, and build capacity to handle a large number of samples which are expected in view of the increasing number of new nano products.
- In the context of the environmental exposure to nanotechnology-based material and products, thereby increasing the risk to human (since water resources are

particularly vulnerable to direct and indirect contamination with nano-materials), in particular, evaluate the potential toxicity and environmental implications of nano-materials to aquatic organisms.

- Create network of qualified and certified dealers, trained applicators and other personnel to promote quality products and to minimize problems at the field level. Compliance to the prescribed schedules and guidelines for the handling, storage, packaging, transportation, etc. of the products must be enforced from the time of their manufacture until the field impact assessment, with effective deterrents against any substandard approaches.

5.2.2 Build necessary human resources, Investment and Institutions

- Initiate resident instructions and curricula on agricultural nanotechnology at selected agricultural universities and link the concerned institutions. To begin with, a minimum of 5 students may be sponsored at Ph.D. level for degree in agricultural nanotechnology.

- The ICAR may develop MoUs with institutes like BARC, Saha Institute of Nuclear Physics, IUAC etc. to share the costly equipment such as ion beam etc. to functionalize, manipulate, and fabricate nano-materials. As the nanotechnology research and development activities require sophisticated equipment facility in addition to the infrastructure, investment in Agricultural Nanotechnology should be intensified. The private sector should also complement the basic and strategic research undertaken by the public sector through appropriate funding and resource sharing. Leading Physics, Chemistry, Nanotechnology, Nanobiotechnology and Electronics experts should be hired at strategic agricultural institutions to gain insights into products that will quickly flow into the Indian agriculture.

- Enhance public awareness relating to the scope and role of nanotechnology in sustainable natural resource management, pest control and other such related areas through the information media. The extension personnel need to be sensitized as to the usefulness of nanotechnology. The Krishi Vigyan Kendras (KVKs) should be equipped to undertake this exercise.

- Expose concerned agricultural scientists, extension workers and students to the developments in nano-science and technology through periodic trainings at selected ICAR or other national institutes as well as at leading institutions abroad, and strengthen selective international collaboration.

- ✦ Review the technological application of nano-products through the regulatory processes, keeping in view the social, political and cultural implications based on an integrated effort of different subject matter specialists, planners and stake-holders.

- ✦ Since currently our preparedness in Agricultural Nanotechnology, particularly for risk assessment research, is inadequate for providing the desired scientific support to the regulatory process, a "National Institute of Agricultural Nano-Technology and Nano-Safety" should be established with the state-of-art infrastructure, human resource and research programmes for conducting frontier research, capacity building in this field and providing policy support and technical advice to the government.

REFERENCES

Amine, A., Mohammadi, H., Bourais, I. and Palleschi, G. (2006). Enzyme inhibition-based biosensors for food safety and environmental monitoring. *Biosensors and Bioelectronics* **21,** 1405-1423.

Chinnamuthu, C. R. and Kokiladevi, E. (2007). Weed management through nanoherbicides. **In:** Application of nanotechnology in agriculture. C.R. Chinnamuthu, B. Chandrasekaran, and C. Ramasamy (Eds.) Tamil Nadu Agricultural University, Coimbatore, India.

Hillie, T. and Hlophe, M. (2007). Nanotechnology and the challenge of clean water. *Nature Nanotechnology* **2**, 663–664.

Hong, S., Leroueil, P. R., Majoros, I. J., Orr, B. G., Baker, J. R. and Banaszak Holl, M. M. (2007). The binding avidity of a nanoparticle based multivalent targeted drug delivery platform. *Chemical Biology* **14,** 107-115.

Hu, Y., Shen, G., Zhu, H. and. Jiang, G. (2010). A class-specific enzyme-linked immunosorbent assay based on magnetic particles for multiresidue organophosphorus pesticides. *Journal of Agricultural and Food Chemistry* **58,** 2801–2806.

Khodakovskaya, M., Dervishi, E., Mahmood, M., Yang Xu, Zhongrui Li, Watanabe, F. and Biris, A.S. (2009). Carbon nanotubes are able to penetrate plant seed coat and dramatically affect seed germination and plant growth. *ACS Nano* **3,** 3221–3227.

Leistritz, F.L., Hodur, N.M., Senechal, D.M., Stowers, M.D., McCalla, D. and Saffron, C.M. (2007). *Biorefineries using Agricultural Residue Feedstock in the Great*

Plains AAE Report 07001 Working Paper, Agricultural Experiment Station, North Dakota State University, Fargo North Dakota.

Mathew, A.P., Laborie, M.P. and Oksman, K. (2009). Cross-Linked Chitosan/Chitin Crystal Nanocomposites with Improved Permeation Selectivity and pH Stability. *Biomacromolecules,* 10, 1627.

NRC (National Research Council) (2008). *Emerging technologies to benefit farmers in sub-Saharan Africa and South Asia.* Washington, D.C.: National Academies Press.

OECD and Allianz (2008). *Sizes that matter: Opportunities and risks of nanotechnologies*. Report in cooperation with the OECD International Futures Programme. http://*www.oecd.org/dataoecd/32/1/44108334.pdf.*

Salamanca-Buentello, F., Persad, D. L. , Court, E. B., Martin, D. K., Daar, A. S. and Singer, P. A. (2005). Nanotechnology and the developing world. *PLoS Medicine* **2,** 383–386.

Subramanian, K. S. and Tarafdar, J. C. (2011). Prospects of nanotechnology in Indian farming. *Indian Journal of Agricultural Sciences* **81,** 887-893.

Tarafdar, J.C. (2012). Perspectives of nanotechnological applications for crop production. *NAAS News* **12,** 8-11.

Tarafdar, J.C., Raliya, R. and Rathore, I. (2012a). Microbial synthesis of phosphorus nanoparticles from Tri-calcium phosphate using *Aspergillus tubingensis* TFR-5. *Journal of Bionanoscience* **6,** 84-89.

Tarafdar, J.C., Agrawal, A., Raliya, R., Kumar, P., Burman, U. and Kaul, R.K. (2012b). ZnO nanoparticles induced synthesis of polysaccharides and phosphatases by *Aspergillus* fungi. *Advanced Science, Engineering and Medicine* **4,** 1-5.

Tarafdar, J.C., Xiang, Y., Wang, W.N., Dong, Q. and Biswas, P. (2012c). Standardization of size, shape and concentration of nanoparticle for plant application. *Applied Biological Research* **14,** 138-144.

Verma, A. K., Singh, V. P., and Vikas, P. (2012). Application of nanotechnology as a tool in animal products processing and marketing: an overview. *American Journal of Food and Technology* DOI : 10.3923/ajft.2012.

List of Participants

1. Prof. R.B. Singh, NAAS, New Delhi
2. Prof. Anwar Alam, NAAS, New Delhi
3. Dr. J.C. Tarafdar, CAZRI, Jodhpur
4. Dr. Tapan Adhikari, IISS, Bhopal
5. Dr. (Mrs.) Tinku Basu, AMITY Institute of Nanotechnology, Noida, UP
6. Dr. R. Baswaraj, CPRI, Shimla
7. Dr. Deepa Bhagat, NBAII, Bangalore
8. Dr. (Mrs.) Arpita Bhattacharya, AMITY Institute of Nanotechnology, Noida, UP
9. Dr. P.S. Brhmanand, DWM, Bhubaneswar
10. Dr. P.K. Chhonkar, IARI Adjunct Faculty, New Delhi
11. Dr. S.C. Datta, IARI, New Delhi
12. Dr. H.S. Gehlot, JNVU, Jodhpur
13. Dr. A. Jeevalatha, CPRI, Shimla
14. Dr. Anu Kalia, PAU, Ludhiana
15. Dr. Gautam Kaul, NDRI, Karnal
16. Prof. A.S. Khanna, IIT, Mumbai
17. Prof. Sunita Kumbhat, JNVU, Jodhpur
18. Dr. Bimlesh Mann, NDRI, Karnal
19. Prof. Siddhartha S. Mukhopadhyay, PAU, Ludhiana
20. Dr. (Mrs.) Ranu Nayak, Amity Institute of Nanotechnology, Noida, UP
21. Dr. A.K. Pal, CIFE, Mumbai
22. Dr. A.K. Patra, IARI, New Delhi
23. Dr. Ram Prasad, AIMT, Noida, UP
24. Dr. Ramesh Raliya, CAZRI, Jodhpur
25. Dr. Indira Rathore, CAZRI, Jodhpur
26. Dr. Dipankar Saha, CAZRI, Jodhpur
27. Dr. Vinod Saharan, MPUAT, Udaipur
28. Dr. S.K. Sanyal, Former Vice-Chancellor, BCKV, Mohanpur, WB
29. Dr. R.P. Singh, Amity Institute of Nanotechnology, Noida, UP
30. Dr. V.K. Singh, PDFSR, Modipuram, Meerut
31. Dr. O.P. Sinha, Amity Institute of Nanotechnology, Noida, UP
32. Dr. K. Sowjanya Sree, AIMT, Noida, UP
33. Prof. K.S. Subramanian, TNAU, Coimbatore
34. Prof. Ajit Varma, Amity University, Noida
35. Dr. N. Vegneswaran, CIRCT, Mumbai
36. Dr. Arunava Goswami, ISI, Kolkata
37. Dr. M.R. Khan, Amity Institute of Nanotechnology, Noida, UP
38. Dr. S.S. Simon, Amity Institute of Nanotechnology, Noida, UP

Note: The designations and affiliations of the participants are as on the date of BSS.

NAAS Documents on Policy Issues*

1. Agricultural Scientist's Perceptions on National Water Policy - 1995
2. Fertilizer Policy Issues (2000-2025) - 1997
3. Harnessing and Management of Water Resources for Enhancing Agricultural Production in the Eastern Region - 1998
4. Conservation, Management and use of Agro-biodiversity - 1998
5. Sustainable Agricultural Export - 1999
6. Reorienting Land Grant System of Agricultural Education in India - 1999
7. Diversification of Agriculture for Human Nutrition - 2001
8. Sustainable Fisheries and Aquaculture for Nutritional Security - 2001
9. Strategies for Agricultural Research in the North-East - 2001
10. Globalization of Agriculture: R & D in India - 2001
11. Empowerment of Women in Agriculture - 2001
12. Sanitary and Phytosanitary Agreement of the World Trade Organization Advantage India - 2001
13. Hi-Tech Horticulture in India - 2001
14. Conservation and Management of Genetic Resources of Livestock - 2001
15. Prioritization of Agricultural Research - 2001
16. Agriculture-Industry Interface: Value Added Farm Products - 2002
17. Scientists' Views on Good Governance of An Agricultural Research Organization - 2002
18. Agricultural Policy: Redesigning R & D to Achieve It's Objectives - 2002
19. Intellectual Property Rights in Agriculture - 2003
20. Dichotomy Between Grain Surplus and Widespread Endemic Hunger - 2003
21. Priorities of Research and Human Resource Development in Fisheries Biotechnology - 2003
22. Seaweed Cultivation and Utilization - 2003
23. Export Potential of Dairy Products - 2003
24. Biosafety of Transgenic Rice - 2003
25. Stakeholders' Perceptions On Employment Oriented Agricultural Education - 2004
26. Peri-Urban Vegetable Cultivation in the NCR Delhi - 2004
27. Disaster Management in Agriculture - 2004
28. Impact of Inter River Basin Linkages on Fisheries - 2004
29. Transgenic Crops and Biosafety Issues Related to Their Commercialization in India - 2004
30. Organic Farming: Approaches and Possibilities in the Context of Indian Agriculture - 2005
31. Redefining Agricultural Education and Extension System in Changed Scenario - 2005
32. Emerging Issues in Water Management The Question of Ownership - 2005
33. Policy Options for Efficient Nitrogen Use - 2005
34. Guidelines for Improving the Quality of Indian Journals & Professional Societies in Agriculture and Allied Sciences - 2006
35. Low and Declining Crop Response to Fertilizers - 2006
36. Belowground Biodiversity in Relation to Cropping Systems - 2006
37. Employment Opportunities in Farm and Non-Farm Sectors Through Technological Interventions with Emphasis on Primary Value Addition - 2006
38. WTO and Indian Agriculture: Implications for Policy and R&D - 2006
39. Innovations in Rural Institutions: Driver for Agricultural Prosperity - 2007
40. High Value Agriculture in India: Prospects and Policies - 2008
41. Sustainable Energy for Rural India - 2008
42. Crop Response and Nutrient Ratio - 2009
43. Antibiotics in Manure and Soil A Grave Threat to Human and Animal Health - 2010
44. Plant Quarantine including Internal Quarantine Strategies in View of Onslaught of Diseases and Insect Pests - 2010
45. Agrochemicals Management: Issues and Strategies - 2010
46. Veterinary Vaccines and Diagnostics - 2010
47. Protected Agriculture in North-West Himalayas - 2010
48. Exploring Untapped Potential of Acid Soils of India - 2010
49. Agricultural Waste Management - 2010
50. Drought Preparedness and Mitigation - 2011
51. Carrying Capacity of Indian Agriculture - 2011
52. Biosafety Assurance for GM food Crops in India - 2011
53. Ecolabelling and Certification in Capture Fisheries and Aquaculture - 2012
54. Integration of Millets in Fortified Foods - 2012
55. Fighting Child Malnutrition - 2012
56. Sustaining Agricultural Productivity through Integrated Soil Management - 2012
57. Value Added Fertilizers and Site Specific Nutrient Management (SSNM) - 2012
58. Management of Crop Residues in the Context of Conservation Agriculture - 2012
59. Livestock Infertility and its Management - 2013
60. Water Use Potential of Flood-affected and Drought-prone Areas of Eastern India - 2013
61. Mastitis Management in Dairy Animals - 2013
62. Biopesticides – Quality Assurance - 2013

***For details visit web site: http://www.naasindia.org**