Nanotechnology for greater agricultural productivity

Dr. D. A. S. Siriwardhana
Sri Lanka Institute of Nanotechnology

Currently, the major challenges encountered by world agriculture include urbanization, changing climate, sustainable use of natural resources and environmental issues like runoff and accumulation of pesticides and fertilizers. These problems are further intensified by an alarming increase in food demand that will be needed to feed an estimated world population of 9 billion by 2050. In addition to that decreasing of world petroleum resources and new arable soil exaggerate the world food crisis.

This above-mentioned scenario is intensively revealed in developing countries as the agriculture is the backbone of the national economy in these countries. They face many critical issues such as lack of new arable soil, reduction of the current agricultural land due to competing economic development activities, commodity dependence, poverty and malnutrition. Several structural changes in the agricultural sector have arisen due to the fast development of technological innovations. For developing countries, advancement in science and technology can offer potential solutions for discovering value addition in their current production systems. Many technologies have been developed that have the potential to increase agricultural productivity and also reduce the environmental and resource costs related with agricultural production. These teohnologies have the ability to conserve land and water by increasing yields through the application of the same or fewer inputs, ultimately conserving the environment.

Among the many advancements in science, nanotechnology is being visualized as a rapidly evolving field that has potential to revolutionize agriculture and food systems. Nanotechnology involves the characterization, fabrication and manipulation of structures, devices or materials that have at least one dimension that is approximately 1 – 100 nm in length. It deals with the physical, chemical and biological properties of matter considered at nanoscale and their implications for the welfare of human beings. When particle size is reduced below this threshold, the resulting material exhibits physical and chemical properties that are significantly different from the properties of macroscale materials composed of the same substance.

There are a number of nanotechnological applications in agriculture, but these are mostly at the bench-top exploration stage. However, it is very likely that in the near future, agriculture and the food sector will see large-scale applications. Nanotechnology has the potential to revolutionize the agricultural and food industry with new tools for the molecular treatment of diseases, rapid disease detection, enhancing the ability of plants to absorb nutrients etc. Smart sensors and smart delivery systems help the agricultural industry combat viruses and other crop pathogens. Nanostructured catalysts are available at experimental level which increases the efficiency of pesticides and herbicides, allowing lower doses to be used. Nanotechnology also protects the environment indirectly through the use of alternative energy supplies, and filters or catalysts to reduce pollution and clean-up existing pollutants. In the agricultural sector, nanotechnology research and development is likely to facilitate and frame the next stage of development of genetically modified crops, animal production inputs, chemical pesticides and precision farming techniques.

Precision farming

In general, precision agriculture is a new attitude in farm management. Precision agriculture means that there is a system controller for each growth factor such as nutrition, light, temperature, etc. Available information for planting and harvest time are collected and controlled by satellite systems. This system allows the farmer to know, when is the best time for planting and harvesting to avoid of encountering bad weather conditions. Best time to achieve the highest yield, best use of fertilizers, irrigation, lighting and temperature are all controlled by these systems. An important nanotechnology role is the use of sensitive nuclear links in GPS systems controller. While nano-chemical pesticides are already in use, other applications are still in their early stages, and it may be many years before they are commercialized. These applications are largely intended to address some of the limitations and challenges facing large-scale, chemical and capital intensive farming systems. This includes the fine-tuning and more precise micro-management of soils; the more efficient and targeted use of inputs; new toxin formulations for pest control; new crop and animal traits; and the diversification and differentiation of farming practices and products within the context of large-scale and highly uniform systems of production.

Applications of nanotechnology in pests and plant diseases management

Currently, the use of chemicals such as pesticides, fungicides and herbicides is the fastest and cheapest way to control pests and diseases. Also biological control methods are comparatively expensive. Uncontrolled use of pesticides has caused many problems such as: adverse effects on human health, adverse effects on pollinating insects and domestic animals, and entering this material into the soil and water and its direct and indirect effect on ecosystems. Intelligent use of chemicals on the nano scale can be a suitable solution for this problem. These materials are used into the part of plant that was attacked by disease or pest. Also these carriers in nano scale has self-regulation, this means that the medication on the required amount only be delivered into plant tissue.

Nanotechnology helps agricultural sciences and reduce environmental pollution by production of pesticides and chemical fertilizers by using the nano particles and nano capsules with the ability to control or delayed delivery, absorption and more effective and environmentally friendly; and production of nano-crystals to increase the efficiency of pesticides for application of pesticides with lower dose. Nano particles for delivery of active ingredients or drug molecules will be at its helm in near future for therapy of all pathological sufferings of plants. There are myriad of nano materials including polymeric nano particles, iron oxide nano particles and gold nanoparticles which can be easily synthesized and exploited as pesticide or drug delivery sponges. The pharmacokinetic parameters of these nano particles may be altered according to size, shape, and surface functionalization. They can also be used to alter the kinetic profiles of drug release, leading to more sustained release of drugs with a reduced requirement for frequent dosing. Diseases are one of the major factors limiting crop productivity. The problem with the disease management lies with the detection of the exact stage of prevention. Most of the times pesticides are applied as a precautionary manner leading to the residual toxicity and environmental hazards and on the other hand application of pesticides after the appearance of disease leads to 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 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 diseases particularly viral diseases. Nano-based viral diagnostics, including multiplexed diagnostic kit development, have taken momentum in order to detect the exact strain of virus and stage of application of some therapeutic to stop the disease. Detection and utilization of bio-markers that accurately indicate disease stages is also a new area of research. Measuring differential protein production in both healthy and diseased states leads to the identification of the development of several proteins during the infection cycle. These nano-based diagnostic kits not only increase the speed of detection but also increase the power of the detection. In the future, nano scale devices with novel properties could be used to make agricultural systems "smart". For example, devices could be used to identify plant health issues before these become visible to the farmer. Such devices may be capable of responding to different situations by taking appropriate remedial action. If not, they will alert the farmer to the problem. In this way, smart devices will act as both a preventive and an early warning system. Such devices could be used to deliver chemicals in a controlled and targeted manner in the same way as nano medicine has implications for drug delivery in humans.

Applications of nanotechnology in food industry

Oxygen is a problematic factor in food packaging, because it can cause food spoilage and discoloration. One of the applications of nanotechnology in the food industry is developing new plastic for food packaging industry. The nano particles are used in the production of these plastics. Nano particles have been found to zigzag in the new plastic, and preventing the penetration of oxygen as a barrier. In other words, the oxygen for entry into package should during longer route, and hence with the long route for oxygen molecules, food can be spoiled later. Recently, nano-coatings are produced for fruit that covering the fruits completely, and prevent of fruit weight loss and shrinkage. Developing smart packaging to optimize product shelf-life has been the goal of many companies. Such packaging systems would be able to repair small holes/tears, respond to environmental conditions (e.g. temperature and moisture changes), and alert the customer if the food is contaminated. Nanotechnology can provide solutions for these, for example modifying the permeation behavior of foils, increasing barrier properties(mechanical, thermal, chemical, and microbial), improving mechanical and heat-resistance properties, developing active antimicrobial and antifungal surfaces, and sensing as well as signaling microbiological and biochemical changes. With the coated enzymes by nanotechnology, we can keep them away of environment and prevent of working them. Thus, the nutrients corruption will be postponed and their longevity increases. Ethylene absorbent is the most important material that is produced by nanotechnology.

Absorbent ethylene nano materials, absorbs ethylene gas that is produced by fruits (fruit decay increases by ethylene gas) and increases persistence of fruit for long periods. Nano bar-codes and nano processing could also be used to monitor the quality of agricultural produce. Scientists at Cornell University used the concept of grocery bar-codes for cheap, efficient, rapid and easy decoding and detection of diseases. They produced microscopic probes or nano bar-codes that could tag multiple pathogens in a farm which can easily be detected using any fluorescent-based equipment. This on-going project generally aims to develop a portable on-site detector which can be used by non-trainedindividuals. With the advent of nanotechnology, nano-based bar codes are also available which can do the same function as that of conventional bar codes, thereby helping in tracking and controlling the quality of food product and give all relevant details in a minute. Biosensor is composed of a biological component, such as a cell, enzyme or antibody, linked to a tiny transducer, a device powered by one system that then supplies power (usually in another form) to a second system. The biosensors detect changes in cells and molecules that are then used to measure and identify the test substance, even if there is a very low concentration of the tested material. When the substance binds with the biological component, the transducer produces a signal proportional to the quantity of the substance. So if there is a large concentration of bacteria in a particular food, the biosensor will produce a strong signal indicating that the food is unsafe to eat. With this technology, mass amounts of food can be readily checked for their safety of consumption.

Nanotechnology in fertilizers

Nitrogen, which is a key nutrient source for food, biomass, and fibre production in agriculture, is by far the most important element in fertilizers when judged in terms of the energy required for its synthesis, tonnage used and monetary value. However, compared with amounts of nitrogen applied to soil, the nitrogen use efficiency (NUE) by crops is very low. Between 50 to 70% of the nitrogen applied using conventional fertilizers — plant nutrient formulations with dimensions greater than 100 nm — is lost owing to leaching in the form of water soluble nitrates, emission of gaseous ammonia and nitrogen oxides, and long-term incorporation of mineral nitrogen into soil organic matter by soil microorganisms. Numerous attempts to increase the NUE have so far met with little success, and the time may have come to apply nanotechnology to solve some of these problems.

Carbon nanotubes were recently shown to penetrate tomato seeds, and zinc oxide nanoparticles were shown to enter the root tissue of ryegrass. This suggests that new nutrient deliverysystems that exploit the nanoscale porous domains on plant surfaces can be developed. A nanofertilizer refers to a product that delivers nutrients to crops in one of three ways. The nutrient can be encapsulated inside nanomaterials such as nanotubes or nanoporous materials, coated with a thin protective polymer film, or delivered as particles or emulsions of nanoscale dimensions. Owing to a high surface area to volume ratio, the effectiveness of nanofertilizers may surpass the most innovative polymer-coated conventional fertilizers, which have seen little improvement in the past ten years. Ideally, nanotechnology could provide devices and mechanisms to synchronize the release of nitrogen from fertilizers with its uptake by crops; the nanofertilizers should release the nutrients on-demand while preventing them from prematurely converting into chemical/gaseous forms that cannot be absorbed by plants. This can be achieved by preventing nutrients from interacting with soil, water and microorganisms, and releasing nutrients only when they can be directly internalized by the plant. Examples of these nanostrategies are beginning to emerge. Zinc–aluminium layered double-hydroxide nanocomposites have been used for the controlled release of chemical compounds that regulate plant growth. Improved yields have been claimed for fertilizers that are incorporated into cochleate nanotubes (rolled-up lipidbilayer sheets). The release of nitrogen by urea hydrolysis has been controlled through the insertion of urease enzymesinto nanoporous silica. Although these approaches are promising, they lack mechanisms that can recognize and respond to the needs of the plant and changes in nitrogen levels in the soil. The development of functional nanoscale films and devices has the potential to produce significant gains in the NUE and crop production. In addition to increasing the NUE, nanotechnology might be able to improve the performance of fertilizers in other ways. For example, owing to its photocatalytic property, nano TiO_2 has been incorporated into fertilizers as a bactericidal additive. Moreover, TiO_2 may also lead to improved crop yield through the photo-reduction of nitrogen gas. Furthermore, nanosilica particles absorbed by roots have been shown to form films at the cell walls, which can enhance the plant's resistance to stress and lead to improved yields. Clearly, there is an opportunity for nanotechnology to have a profound impact on energy, the economy and the environment, by improving fertilizer products.

1. *Chen, H., and R. Yada* (2011): Nanotechnologies in agriculture: New tools for sustainable development. *Trends in Food Science & Technology* 22, 585.
2. *Ditta, A.* (2012): How helpful is nanotechnology in agriculture? *Adv. Nat. Sci.: Nanosci. Nanotechnol.* 3, 1.
3. *Joseph, T., and M. Morrison* (2006): Nanotechnology in Agriculture and Food: A Nanoforum Report.,
4. *Sharon, M., A. K. Choudhary, and R. Kumar* (2010): Nanotechnology in agricultural diseases and food safety. *Journal of Phytology* 2, 83

~~~*~~~

Global Environmental Impacts of Agriculture: Requirement for sustainable agricultural practices to save the world

Professor Priyani A. Paranagama

Senior Professor of Chemistry (Chair), Department of Chemistry, University of Kelaniya

Introduction

World population is predicted to reach about nine billion in 2050 indicating an increase demand for agricultural produce and will continue to grow in the future. Increased population exerts further pressure on increased production of food, fiber, biofuel and other essential needs. Therefore, agriculture is an important sector that is directly related to the economic growth of a country. Although food, fiber, biofuel, drugs are produced in large quantities to sustain and enhance quality of human life, many environmental problems faced today are due to the activities of the agriculture which have been directly associated with the intensification of food production. If the agricultural practices which have been introduced in past two decades are continued without a change, the agriculture related environmental problems will remain as serious issues during the next decade. Although development of sustainable agriculture with increased food production of an ever-changing planet is a challenge, there is an urgent need for major changes of the global agriculture systems. It is evident that sustainability of agriculture depends on generation of environmentally friendly, economically viable and socially acceptable products and the balance of these three major factors is extremely important in order to maintain sustainability of the agriculture. It is similar to a 3-legged stool while sustainable agriculture is on the top of the stool. If one leg of the stool is broken, the stool is not stable and will fall over indicating priority should be given to these three key factors which directly affect on the sustainable agriculture and it is clearly shown that agriculture today is largely a struggle against nature.

This paper reviews the presentation I made at the theme seminar of the annual sessions of the Institute of Chemistry Ceylon and discussed the effects of key activities related to the global agriculture that have contributed significantly to global environmental impacts.

Negative impacts of Green revolution

In this section I am highlighting the causes and effects of modern agriculture that was introduced after the green revolution. In 196o's the green revolution has been introduced by Nobel laureate, Norman Borlaug, who was called "Father of the Green Revolution". It was initiated with the intention to address the issues of malnutrition in the developing world, mainly targeted to increase the agricultural productivity. The technology of the Green Revolution involved generation of High Yielding Verities (HYV) using selectively breed or genetically-engineered crops that work in combination with the use of chemical fertilizers, synthetic pesticides and high inputs of water to increase crop yields. The technology of green revolution was readily initiated in developed countries and later the developing countries (eg. Sri Lanka) were also following a similar trend to increase the food production. It was reported that fast growing dwarf
~~~

varieties of rice and wheat were developed for tropics and subtropics in 1967 to increase the yield of these crops and seeds were distributed among the farmers (Hedden, 2003). Since growth of the new HYV heavily needs fertilizers, pesticides and high inputs of water, there were many poor farmers who could not afford to participate in the Green Revolution. Hence the gaps between social classes were widen as wealthy farmers got comfortable and poor farmers lagged behind. Consequently, subsistence agriculture in which the farmers focus on growing enough food to feed themselves and their families was transformed to commercial agriculture which is performed using monocultures of HYV. The techniques used for monocultures involved the development of high-yielding varieties of cereal grains, vegetables etc., expansion of irrigation infrastructure, modernization of management techniques, distribution of hybridized seeds, encourage the use of synthetic fertilizers and pesticides to farmers and high inputs of water. The only target of commercial agriculture was to increase agricultural productivity and the yield in order to make a higher income. The use of HYV was novel to traditional farmers and most of them did not have sufficient cash to purchase new machineries introduced via green revolution. The farmers were not adequately educated to understand the environmental impacts that cause due to change of the agriculture systems. The research and development programmes were diverted only towards to create HYV and increase the productivity of crops. Only few researches concentrate their research on the environmental impacts although that was not strong enough to convince the relative authorities. To encourage the farmers on use of HYV and high input monoculture, a loan scheme was created to provide farmers to purchase new seeds, fertilizers, pesticides etc. and marketing systems were also introduced to sell their crops. Facilities were provided to farmers through them farmers can purchase fertilizers, pesticides or machineries. Thus, local farmers tend to produce cash crops for export rather than food crops or subsistence crops for local consumption. Consequences of introduction of commercial agriculture are given below (Mahaliyanaarachchi, *et al.*, 2006).

- The agricultural productions are aimed mainly for sales.
- Productions are targeted for profit maximization.
- The satisfaction of different needs of consumers and interests of consumers are aimed.
- Less attention for nutritional quality and food security
- Implies the concepts of agri-business management

Criticisms of the Green Revolution

It was found that agriculture developed through the green revolution has greater harmful environmental impacts than any human activity as cash crops tend to develop adverse, long term environmental problems. Therefore it has been highly criticized among the scientists and traditional farmers who are concerned on the negative effects of the green revolution due to the reasons given below (Kang, D.S., 1982).

- Gap between rich and poor farmers is widen because rich farmers have the resources for fertilizer, pesticides, irrigation water, machinery, storage and transportation
- Colour, texture and tastes of new crop varieties not well received.
- Production of HYV's are not cost effective and therefore high costs for small farmers
- Many HYVs require more labour than the traditional counterparts (irrigation and fertilization)
- Require heavy use of synthetic fertilizers and pesticides; salt build-up and contamination of watersheds by nitrates, phosphates and pesticide residues
- Farmers rely on a few strains of a plant and adapted to monocultures, a new disease can wipe out a large portion of the harvest
- Use of machinery causes sound pollution and air pollution
- More benefits only for larger landholders

Negative impacts of current mass production style of farming

- Large-scale commercial farming is practically no different from large industrial enterprises as the main objective of commercial agriculture is achieving higher profits through maximization of crop yields per hectare. The Green Revolution changed the evolutionary history of crops by changing the fundamental nature of seeds and causes extinction of species because of destruction of natural habitat. The increase of global food production has led the serious environment damages in a variety of ways and some are given below.

- Reduced biodiversity
- Habitat destruction
- Deforestation
- Water, air and soil pollution
- Salinization, desertification

• Decline in water resources

It has been reported that nearly 30% of the world's cropland has been degraded to some degree by deforestation (Barrow, C.J. 1991). Deforestation is the permanent destruction of forests on a massive scale in order to make the land available for other uses. As a result of deforestation, ecosystems of the rainforest are converted into less bio-diverse ecosystems such as pasture, cropland or plantations (Kricher, 1997) and these lands were used for cultivation of monoculture crops. The environmental impacts cause due to monoculture crops are an enhancement of greenhouse gas emission (approximately 20% of the world greenhouse gas emission is accounted for deforestation), increase in pest population (as monoculture enables pests to have continual supply of food), increase in application of synthetic fertilizer (increase salt built up and toxic elements in soil), exhaustion of particular type of minerals (the same type of plants draws particular types of mineral from the soil for a long time), cause extinction of species because of destruction of natural habitat (It has been estimated that we are losing 135-140 plant, animal and insect species every single day due to rainforest deforestation) and soil erosion (soil erosion is also caused by heavy rains or strong winds after the deforestation).

The burning of biomasses after the deforestation, releases greenhouse gases such as CO_2, CO, N_2O, CH_4, various CFCs and other trace gases into the atmosphere. Various forms of agricultural production may lead to significant trace gas emissions. Tilling of soils permits oxidation of organic matter and atmospheric CO_2 concentration increases. Use of nitrogenous fertilizer, however, increases nitrous oxide emissions from soil and water through nitrification and denitrification processes. Application of fertilizers increases the N_2O release by plants, although emission rates vary greatly with soil condition (Follett, 2005).

Since, the above factors affect on human health, human wealth and nature's health, for the past several years research has looked at sustainable agriculture as a potential solution to correct and prevent these problems. In my opinion, the above problems can be minimized by practicing sustainability and by understanding the balances between ecological and social systems. However it is reported that the green revolution has brought disasters to most of the people and the ecological system (Shiva, Vandana, 1991) and however, people with different environmental world views often disagree about the seriousness of environmental problems and major harmful environmental effects caused due to agricultural practices introduced through the green revolution.

Another concern of the modern agriculture is loss of genetic diversity of food plant after introduction of global genetically modifed food (GM). In Sri Lanka, about 97% of the food plant varieties available in 1940 no longer exist in large quantities now. Possible environmental and health risks of GM foods are increasingly well documented. However, peer-reviewed scientific evidences to indicate environmental and health impacts of GM crops are given below.

- Toxic to harmless non-target species (Long-term exposure to pollen from GM insect-resistant maize causes adverse effects on the behavior and survival of the monarch butterfly, America's most famous butterfly (Dively, et al. 2004).
- Toxic to beneficial insects. GM Bt crops adversely affect beneficial insects important to controlling pests, such as green lacewings (Obrist, et al., 2006).
- Since many GM crops secrete their toxin from the roots into the soil, the active GM residues may be toxic and long term cumulative effects of the GM toxin are of concern (Icoz, & Stotzky, 2008).
- Plant parts of GM corps can enter the aquatic systems and the toxins can accumulate in aquatic plant and exert toxic effect demonstrating complexity of interactions in the natural environment (Cambers, et al., 2010).
- Since plant insect interactions are complex, several scientific studies show that new pests are filling the void left by the absence of rivals initially controlled by GM crops (Cloutier, et al., 2008).
- Herbicide-tolerant crops can cross-pollinate with weeds, resulting in "superweeds". Therefore increasing amounts of glyphosate or additional herbicides are needed to control these 'superweeds' (Duke, 2005).

Excessive use of fertilizers, pesticides and impact on public health

The long-term use of fertilizers and pesticides has been shown to have detrimental effects on human health and overall soil health that leads to erosion. Leaching of nutrients and eutrophication of waters are key negative impacts of environment causes due to excessive use of fertilizer. Eutrophication is a condition in an aquatic ecosystem where high nutrient concentrations stimulate growth of algae. This leads to intesnse growth of aquatic plants, increased oxygen consumption and production of excess organic matter. Non-organic fertilizers mainly contain phosphate, nitrate, ammonium and potassium salts are considered to be potential source of natural radionuclides and heavy metals (Chandrajith, et al., 2009). It has been reported that fertilizer contains a large majority of the heavy metals like Hg, Cd, As, Pb, Ni, and Cu; natural radionuclide like ^{238}U, ^{232}Th, and ^{210}Po (FAO, 1999). However, in recent years, fertilizer consumption increased exponentially throughout the world, causes serious environmental problems. In addition to the eutrophication, fertilization may affect the accumulation of heavy metals in soil and plant system. Plants absorb the toxic elements in fertilizers through the soil and they can enter the food chain. Thus, fertilization leads to water, soil and air pollution.

Sri Lanka is currently one of the world leaders in chemical fertilizer consumption, and imports. Table 1 shows the description of chemical fertilizers imported to Sri Lanka in 2010, and it shows urea, triple super phosphate (TSP) and Muriate of potash (MOP) are imported to Sri Lanka in high quantity for cultivation of rice, tea, rubber and coconut to use in the agriculture (Sri Lanka National Fertilizer Secretariat). Since Sri Lanka is an agricultural country, spending on fertilizer imports rose sharply and the expenditure on fertilizer imports increased by 119.4 % in 2011. Among them nitrogen and phosphorus are the major nutrients of concern that are frequently applied in our crop field in Sri Lanka. The average fertilizer imports per annum in Sri Lanka had been around 550,000 - 650,000 metric tonnes. Figure 1 shows the fertilizer imports in Sri Lanka from 2007 to 2011. In 2007, apart from the outflow of foreign exchange, the fertilizer subsidy import bill stands at over Rs 65.5 billion in Sri Lanka (Source: Daily News May 12, 2011). The farmers were convinced that chemical fertilizers are the most important contributor to increase the world agricultural productivity over the past 30 years and the largest user of chemical fertilizer in South Asian Region was Sri Lanka in the year 2008 (Table 2). This amount was approximately 56 % higher than the amount of chemical fertilizer used in Bangladesh, a country where a large number of the population suffers from chronic arsenic toxicity (Allen, *et al.*, 2000).

In Sri Lanka, excessive use of chemical fertilizers in agriculture, resulting in a large number of environmental problems because some fertilizers contain toxic elements (eg. cadmium and arsenic) and high concentrations of radionuclides (Jayasumana, et al., 2011 & Fernando, et al., 2012).

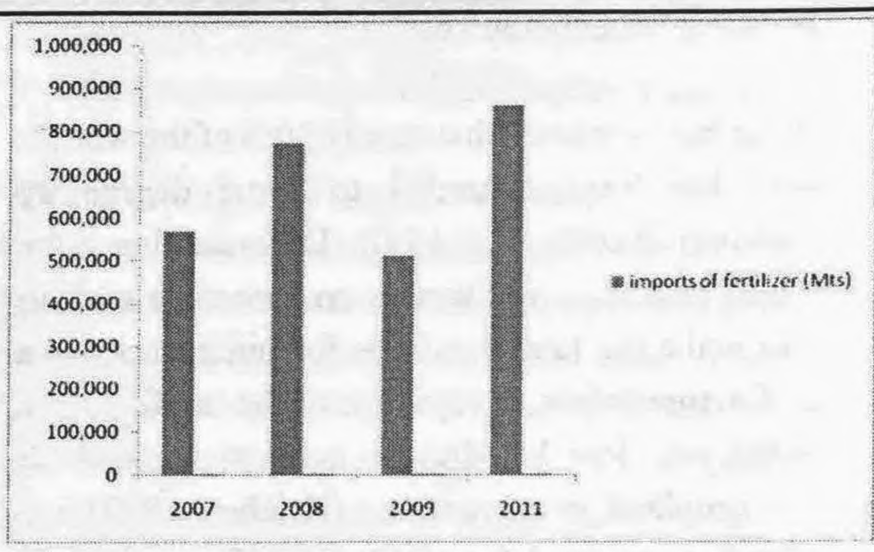

Figure 1: Fertlizer imports in Sri Lanka from 2007 to 2011

Source - FAO Fertilizer Report, 2010

Table 1. Fertilizer consumption in Sri Lanka (2010)

Description of the fertilizer imported to Sri Lanka	Urea*	TPS[1]*	MOP[2]*	Total*
Paddy	308,000	100,000	93,000	501,000
Tea	100,000	37	26,000	126,037
Rubber	3,050	20	2,057	5,127
Coconut	5,340	72	8,156	13,568
Other field crops	2,580	2,247	5,295	10,122
Vegetable	3,287	947	2,355	6,589
Export agriculture sector	808	218	1,109	2,135
All other sectors	14	10	16	40
National consumption	423,079	103,551	137,988	664,618
National requirement	553,400	134,675	248,700	936,775

*Tones [1] Triple Super Phosphate [2] Muriate of Potash

Source; Sri Lanka National Fertilizer Secretariat

A study conducted by a group of researches from University of Peradeniya has also reported that the TSP fertilizer collected from Chronic Kidney Disease with unknown etiology (CKDu) endemic areas contained significantly higher amounts of uranium (200 ppm – 400 ppm) and Cd (Chandrajith, et al., 2009). Samples of fertilizer collected from various parts of Sri Lanka were investigated and it was revealed that most of the inorganic fertilizers containing phosphates that are commonly used in rice farming are contaminated with arsenic and mercury. The highest amount of arsenic contamination in fertilizer was reported from triple super phosphate (TSP) used in cultivation of rice and it was in the range of 25 mg/kg to 37 mg/kg. Since the annual consumption of TSP for cultivation of rice in Sri Lanka is around 1.03 x 10^6 kg in the year 2010, our results revealed that amount of arsenic present in the TSP used in the agriculture in 2010 was around 2071 kg. The organic fertilizer prepared from decomposing plant matter was analyzed and confirmed that presence of arsenic is negligible in organic fertilizer (Fernando, et al. 2012). Therefore it is suggested to encourage farmers to use organic fertilizer and minimize the use of synthetic fertilizer in Sri Lanka and reduce the health problems caused due to excessive use of fertilizer.

Table 2. Annual Chemical fertilizer consumption in South Asian region 2008

No	Country	Fertilizer consumption (Kg/hectare of arable land)
01	Sri Lanka	284.3
02	Bangladesh	164.5
03	Pakistan	163.3
04	India	153.5
05	Bhutan	9.0
06	Nepal	7.7

Source - http://data.worldbank.org/indicator/AG.CON.FERT.ZS

Although use of pesticides includes enhanced economic potential in terms of increased production of food and fiber, they have resulted in serious health implications to man and the environment. There is now overwhelming evidence that some of these chemicals do pose a potential risk to humans, other life forms and unwanted side effects to the environment (Jayasumana, et al., 2013, WHO final report 2012).

Characteristics of an ideal pesticide developed for crop protection should be affects only target pests, harms no other animal or plant species, no genetic resistance, breaks down quickly in the environment (biodegradable) and more cost-effective. Despite the fact that the majority of pesticides available in the market is not targeting the pest and adverse affect on non-target plants and animals. Repeated application of synthetic pesticides develops genetic resistance, leads loss of biodiversity. They persist in soil, leach to groundwater and surface water, cause an increase in other pest species, residual effect, harm wildlife, bioaccumulate in food chains and potential influence in human health.

Most important characteristic feature of synthetic pesticides is persistent of activity (non-biodegradable) and accumulates in plants animals called bioaccumulation and become more concentrated at higher trophic levels of the food chain called biomagnifications. Bioaccumulation and biomagnifications of pesticide in the food chain have been explained using the potent pesticide, DDT.

First warning signals about pesticides danger was pointed out by Rachel Carson in 1962. This was about indiscriminate spraying of pesticides, an example for bioaccumulation of Dichlorodiphenyltrichloroethane (DDT). DDT was developed in 1939 and the inventor was awarded the Nobel Prize as it helped to clear the malaria-causing mosquitoes during World War II. There were only few scientists expressed environmental impacts of this miracle compound. One was nature writer, Rachel Carson, marine biologist from Pennsylvania. She had written a book *'Silent Spring'* to highlight the danger of DDT including the death of numerous birds around her property resulting from the aerial spraying of DDT and was published in 1962. It generated a storm of controversy over the use of chemical pesticides. In 1972, *Silent Spring* facilitated the ban of the pesticide, DDT in USA. Though this is a very old story, it helped to convince the chronic toxicity of pesticides. It describes entering of DDT to the food chain and accumulation in the fatty tissues of animals, including human beings as many pesticides are known to cause cancer and genetic damages. This book changed the view on pesticides and has stimulated public concern on pesticides and their impact on health and the environment (Gilliom, 2007 and http://www.nrdc.org/health/pesticides/hcarson.asp).

The problems of pesticide usage are not over. Although in many countries the old persistent, bioaccumulative pesticides have been banned, a lot of new pesticides have been developed and used in large quantities. For most of the new pesticides appear to have impacts on environment and sufficient amount of knowledge about their possible risks and adverse effects on the environment and chronic toxicity on human are not available.

Another disease of human caused due to contamination of water in Japan is named as Minamata disease and was caused by methyl mercury-contaminated effluent released into Minamata Bay by Chisso chemical factory in Japan in 1930's. It is a neurological syndrome caused by severe mercury poisoning. The effluent that contained methyl mercury was released into Minamata Bay from 1932 to 1968 and methyl mercury is highly toxic chemical, bioaccumulated in shellfish and fish in Minamata Bay. The sea foods were then eaten by the local population in these areas resulted in mercury poisoning. It took more than 38 years to confirm the cause of the disease and therefore the government took no action to stop contamination or prohibit fish consumption until it was confirmed. This is one of the most massive pollution problems to strike Japan and however, after 38 years the Japanese government admitted that methyl mercury was the etiologic agent of Minamata disease. It was also reported that methyl mercury is transferred across the placenta to affect the development of unborn children, resulting in serious mental and physical problems in later life. The researches missed this point at first because of a medical disagreement that such transfer across the placenta was impossible (Harada, 1995). Since methyl mercury is volatile and a lipid soluble compound, it readily and completely absorbed by gastrointestinal tract. It was found to complex with free cysteine, with proteins and peptides containing that amino acid. Therefore the amino acid binds with methyl mercury was recognized by the amino acid transporting proteins as methionine (figure 2). Toxic effects of methyl mercury are well known now and it inhibits acetylcholine synthesis, impairs glycolysis, nucleic acid biosynthesis, aerobic respiration, and protein synthesis and neurotransmitter release. The injured neurons eventually die.

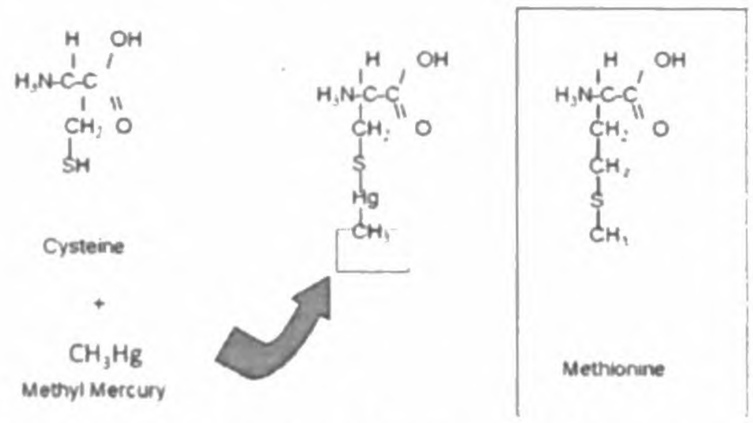

Figure 3. Reaction of meth mercury with cysteine

Similar health problem due to extreme use of agrochemicals has been observed in North Central Province (NCP) of Sri Lanka. During the last two decades, noteworthy numbers of patients with Chronic Kidney Disease were reported from Rajarata area of Sri Lanka especially in Medawachchiya, padaviya, Kebitigollawa, Medirigiriya (North Central Province), Nikawewa (North Western Province), Dehiattakandiya (Eastern Province) and Giradurukotte (Uva Province). Since this is different from other kidney diseases, this was named as Chronic Kidney Disease of unknown etiology (CKDu). CKDu is one of the biggest health issues in Sri Lanka. Majority of CKDu patients in Sri Lanka are farmers and they are heavily exposed to pesticides and fertilizers as very little attention is given to hazardous effects of these agrochemicals on human health. Being a pesticide using farmer who drinks well water has been identified to be of highest risk for CKDu (Wanigasuriya et al. 2007). The most recent publication on possible link of chronic arsenic toxicity with CKDu in Sri Lanka was performed by Jayasumana et al. (2013) with the intention of determining the prevalence of clinical features of Chronic Arsenic Toxicity among CKDu patients in North Central Province, Sri Lanka. It was reported that abnormal skin manifestation were observed among CKDu patients (figure 3).

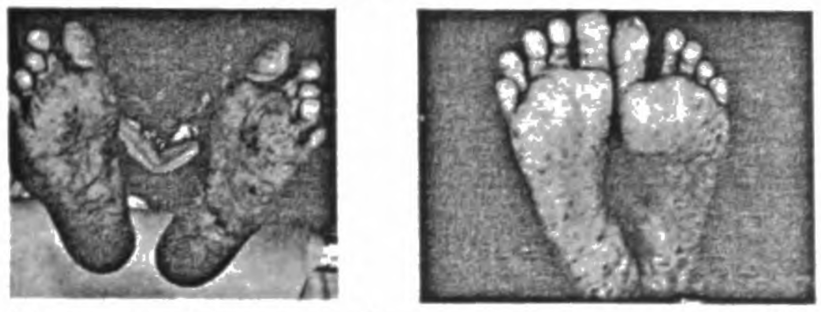

Figure 3. Abnormal skin manifestations of CKDu patients encountered in NCP (Jayasumana, et al., 2013)

In this study the hair and urine samples were collected from both CKDu patients and controls and analyzed for presence of arsenic. The results revealed that hair samples of CKDu patients has significantly higher concentration of arsenic when compared with the control group and 68% of CKDu patients and 28% of the controls had urine arsenic levels above 21 μg/g creatinine, which is considered the point of threshold for manifestation of early renal changes that can be developed in to chronic kidney disease (Jayasumana, et al., 2013). An extensive research on CKDu patients in NCP in Sri Lanka was conducted by WHO (2012) and confirmed the arsenic toxicity among the CKDu patients. Further causative agents for CKDu have been identified and named as nephortoxic agrochemicals, Cd and As (WHO, 2012). Similar CKDu has been reported in some other palace in the world. As in Sri Lanka no exact theory has been formulated yet to explain the etiology for CKD in those occasions. The CKD recently observed among sugarcane farmers in Central America is predominantly affects young males resulting in substantial morbidity and mortality (Orantes et al 2011). Features are most consistent with tubulointerstitial disease. A similar picture is seen in upper Egypt where investigators have noted abnormal increase in CKD patients among male farmers who use Pesticides (kamel et al.2010).

Jayasumana, et al. (2011) has reported that source of arsenic contamination in CKDu patients in Sri Lanka is agrochemicals (both fertilizer and pesticides) used by these farmers. Despite the fact that importation of As-containing pesticides is illegal in Sri Lanka, results reported by Jayasumana, et al., (2011) revealed that 20 out of the 32 available pesticide brands in the local market contained As in the range of 180±14 - 2586±58 μg/kg and it varied depending on the type of active ingredient, brand, batch of pesticides, importer and the area that it is used. World Health Organization classifies pesticides with arsenic compounds as active ingredients to be highly hazardous. Arsenic containing pesticides are thus banned in Sri Lanka since 1995 and it has been officially notified in the extraordinary gazette notification no 1190/24 of the democratic republic of Sri Lanka of 6^{th} June 2001. Arsenic is not even prescribed to include as an inert ingredient, except for six types of pesticides in which it is allowed (within limits) as an impurity and in Sri Lanka, copper- based pesticides only are legally allowed to contain (within limits) arsenic.

Presence of arsenic in locally-grown rice has been reported from Sri Lanka (Jayasekara and Freitas 2004,Yamily et al., 2008 and Chandrajith et al.,2010). Jayasumana (2013) reported the presence of arsenic in hair and urine of patients of Chronic Kidney Disease of unidentified etiology (CKDu) as well as in body parts of diseased CKDu patients from Sri Lanka's largest rice cultivation areas in the North-Central Province. This led to the hypothesis that presence of arsenic compounds in food is a potential cause of CKDu and the agrochemicals containing arsenicals are the potential source of it. It is an urgent need therefore to divert more resources to consolidate these findings and to plan and implement strategies to prevent/ abate pollution of Sri Lankan environment with arsenic derived from agrochemicals. Chronic arsenic poisoning evidently leads to many health hazards and it has been proved substantially that the entry of minute quantities of As to human body in microgram levels over several years can cause many non communicable diseases (Jayasumana, et al., 2013).

Contamination of milk powder with an agrochemical, dicyandiamide (DCD) is another serious health issue in Sri Lanka and this is an example for excessive use of agrochemical as DCD is used to reduce the emission of the greenhouse gas, nitrous oxide from urea. DCD is an effective inhibitor of nitrification enzymes of the bacteria in soil and in addition to the inhibitory activity, it contain 67% nitrogen and is also used as a nitrogen fertilizer as it is converted to ammonia and nitrate in the soil. However high doses of DCD are considered to be toxic for humans and the literature revealed that no extensive research has been conducted on DCD. A recent analysis conducted at ITI reported that milk powder imported from Newzeland and Australia was contaminated with DCD. It is also suspected that the milk powder containing DCD may be an adulteration of milk using nitrogen rich compounds as DCD whcih makes the protein content of milk appear higher than the actual value. In 2007, melamine and cyanuric acid in milk powder and wheat gluten added to pet food, infant formula caused renal failure and sickened and killed large numbers of infants, cats and dogs. There were hundreds of thousands of victims as well as product recalls in many countries. Therefore, it is essential to confirm that traces of dicyandiamide are not found in milk powder imported to Sri Lanka and reassure there is no risk to health.

Considering the above issues, it is no doubt that we should move forward and take necessary precautions to establish sustainable agriculture. During the last 30 years, the agriculture was developed to provide food for growing populations at unsustainable rates. Fertilizers and pesticides are the major pollutants of soil and water in developing countries. Pesticides reduce biodiversity by destroying weeds, insects, the food species of birds and other animals. Hence there will be a growing demand for organic farming, food will be produced without chemical inputs and increased demand for ecological methods of pest control (IPM).

It is realized that protection of natural resources and improve both environmental quality and food security in the more crowded world become extremely difficult with excising agricultureral methods. Therefore sustainable agriculture needs to encompass three key factors, environmentally friendly, socially acceptable and economically viable. By taking this approach, all agriculture systems need to reconsider a certain set of basic principles, which will help to protect natural resources and travel towards more sustainable practices. Land degradation, salinization, the over extraction of water and the reduction of genetic diversity in crops and livestock are the main factors that are affected on the future of sustainable agriculture. Since the long term consequences of these activities are difficult to quantify, adapting sustainable agricultural practices in the future would minimize the impacts of agriculture on the environment and help to address issues related to human health.

Sciencetists from universities and research institutes, private sectors, general public and politicians need work collaboratively to find right technological solutions combined with right policy directions to establish sustainable agriculture and minimize the environmental impacts caused due to existing methods. Consumers can play a critical role in strengthening sustainable agriculture through their purchases of organic food items as the quality of food has influenced consumer choices. Hence it is important to identify the issues that have been affected in developing sustainable agriculture and establish criteria which help to develop sustainable agriculture, implement trade policies that will help to develop sustainable agriculture and propose specific action plan for a sustainable agriculture and ecosystems.

References

1. Allan H. Smith, Elena O. Lingas, & Mahfuzar Rahman, Contamination of drinking-water by arsenic in Bangladesh: a public health emergency, Bulletin of the World Health Organization, 2000, 78(9), 1093 - 1103
2. Barrow, C.J. 1991. *Land Degradation: Development and Breakdown of Terrestrial Environments.* Cambridge: Cambridge University Press.
3. Cambers, CP., Whiles, M.R., Rosi-Marshall, E.J., Tank, J.L., Royer, T.V., Griffiths, N.A., Evans-White, M.A. & Stojak, A.R.. 2010. Responses of stream macroinvertebrates to Bt maize leaf detritus. Ecological Applications 20:1949–1960
4. Chandrajith, R.,S. Nanayakkara., K. Itai, T.N.C. Athuraliya, C.B. Dissanayake and T. Abeysekara.2011. Chronic kidney disease of uncertain etiology in Sri Lanka:geographic distribution and environmental implications. *Environ Geo chem. Health* DOI10.1007/s10653-0109339-1.
5. Chandrajith, R.,S. Nanayakkara., K. Itai, T.N.C. Athuraliya, C.B. Dissanayake and T. Abeysekara.2009, Natural radionuclides and trace elements in rice field soils in relation to fertilizer application: study of a chronic kidney disease area in Sri Lanka, *Environ Geo chem. Health* DOI10.1007/s10653-0109339-1.
6. Cloutier, C.; Boudreault, S. & Michaud, D. 2008. Impact of Colorado potato beetle-resistant potatoes on non-target arthropods: a meta-analysis of factors potentially involved in the failure of a Bt transgenic plant. Cahiers Agricultures 17: 388-394.
7. Dogra, Bharat, (1994) Green Revolution: no joy for the poor In *Return to the good earth – Damaging effects of modern agriculture and the case for ecological farming* (pp. 242-244), (Second edition) Penang, Malaysia, Third World Network
8. Dively, G.P., Rose, R., Sears, M.K., Hellmich, R.L. Stanley-Horn, D.E. Calvin, D.D. Russo, J.M. & Anderson, P.L.. 2004. Effects on monarch butterfly larvae (Lepidoptera: Danaidae) after continuous exposure to Cry1Ab expressing corn during anthesis. Environmental Entomology 33: 1116-1125.
9. Duke, S.O. 2005. Taking stock of herbicide-resistant crops ten years after introduction. Pest Management Science 61: 211–218.
10. Environews Forum. Killer environment. Environ Health Perspect. 1999;107:A62.
11. FAO, (March, 2009). ResourceSTAT-Fertilizer. *Food and Agriculture Organization of the United Nations*. [Online]. Available:http://faostat.fao.org/site/575/Desktop Default.aspx? PageID=575#ancor, 12.03.2009.
12. Fernando, A., Paranagama, P.A., Jayalath, K, Fonseka, S., Amarasinghe, M., Senanayeke, K., Jayasumana, C., Mahamithawa, P., Wijewardhane, C., Samarasinghe, D., Dahanayake, K. (2012) Determination of arsenic content in synthetic and organic manure based fertilizers available in Sri Lanka, *Proceedings of the International Conference on Chemical Sciences,* Sri Lanka Foundation Institute, Colombo 07, Sri Lanka, 20 – 22 June, 32.
13. Follett, R.F., Shafer, S.R., Jawson, M.D. & Franzluebbers, A.J. 2005. Research and implementation needs to mitigate greenhouse gas emissions from agriculture in the USA. Soil and Tillage Research 83(1): 159-166.
14. Harada M, 1995, Minamata disease: methylmercury poisoning in Japan caused by environmental pollution, Crit Rev Toxicol.;25(1):1-24
15. Hedden, P. 2003. The genes of the Green Revolution. *Trends in Genetics*, 19:5–9
16. Icoz, I. & Stotzky, G. 2008. Fate and effects of insect-resistant Bt crops in soil cosystems. Soil Biology & Biochemistry 40: 559–586.
17. Gilliom, R.J. (2007): Pesticides in U.S. Streams and Groundwater. *Environmental Science & Technology* 41(10), pp 3408-3414.
18. Jayasekara, R. and M.C. Freitas. 2005. Concentration levels of major and trace elements in rice from Sri Lanka as determined by the k_0 standardization method *Biological trace element research* 103:83-96.
19. Jayasumana, M.A.C.S., Paranagama, P.A., Amarasinghe, M. D., Wijewardane, K.M.R.C., Dahanayake, K.S., Fonseka, S.I., Rajakaruna, K.D.L.M.P., Mahamithawa, A.M.P., Samarasinghe, U.D., Senanayake, V.K. (2013) Possible link of Chronic arsenic toxicity with Chronic Kidney Disease of unknown etiology in

Sri Lanka, Journal of Natural Sciences Research, 3(1), 64-73.

20. *Jayasumana, M.A.C.S, Paranagama, P. A., Amarasinghe, M.D., Fonseka and S.I, Wijekoon, D.V.K. (2011)* Presence of Arsenic in pesticides used in Sri Lanka, *Proceedings of The Waterprofssionals'day Symposium,* Water Resources Reserch in Sri Lakna, Faculty of Agriculture, University of Peradeniya, 127-141
21. Kamel,E.G.,and O.El-Minshawy. 2010. Environmental Factors Incriminated in the Development of end stage renal disease in El-Minia Governorate, Upper Egypt *Int J Nephrol Urol* 2(3): 431-7.
22. Kang, D.S., (1982), Environmental problems of the Green Revolution with a focus on Punjab, India, in Richard Barett, (ed), *International dimensions of the environmental crisis* (p.204), Boulder, Westview Press
23. Karunakaran C.O. The Kerala food poisoning. J Indian Med Assoc. 1958;31:204. Takashi Yorifuji, Toshihide Tsuda and Masazumi Harada, Minamata disease: a challenge for democracy and justice.
24. Kricher, J. (1997). A Neotropical Companion: An introduction to the animals, plants, & ecosystems of the New World Tropics. New Jersey: Princeton University Press
25. Obrist, L.B., Dutton, A., Romeis, J. & Bigler, F. 2006. Biological activity of Cry1Ab toxin expressed by Bt maize following ingestion by herbivorous arthropods and exposure of the predator Chrysoperla carnea.BioControl 51: 31-48.
26. Orantes, C.M., R. Herrera, M. Almaguer, E.G. Brizuela and C.HE. Hernandez,2011.Chronic kidney disease and associated risk factors in the Bajo Lempa region of El Salvador:Nefrolempa study,2009,MEDICC Review13(4):14-21
27. Rohana P Mahaliyanaarachchi, R M A S Bandara (2006) Commercialization of Agriculture and Role of Agricultural Extension, Sabaragamuwa University journal, 6(1), 13 – 22.
28. Scott Kilman and Roger Thurow. "Father of 'Green Revolution' Dies". The Wall Street Journal. Retrieved 5 June 2013
29. Shiva, Vandana, (1991) *The violence of the Green Revolution – Third world agriculture, ecology and politics,* London, Zed books – Third World Network
30. Sri Lanka National Fertilizer Secretariat, 80/5 Govijana Mandiraya Rajamalwatta Av, Battaramulla, Sri Lanka.
31. Wanigasuriya, K.P.,R.J.Peiris-John, R.Wickremasinghe,A.Hittarage.2007.Chronic renal failure in North Central province of Sri Lanka:an environmentaly induced disease. *Trans R Soc Trop Med Hyg* 101(10):1013-17.
32. Yamily,J.Z.,and J.M.Duxbury.2008.Arsenic in rice - Estimating normal levels of total arsenic in rice grain, *Environmental science and technology* 42(10): 3856-3860.

WHO final report on Investigation and evaluation of Chronic Kidney Disease of Uncertain Aetiology in Sri Lanka, Final Report, World Health Organization (2012), RD/DOC/GC/06.

Accreditation of Graduateship Programme by the Royal Society of Chemistry, UK

RSC | Advancing the Chemical Sciences

Formal recognition has come from the **RSC**, which is the only recognized accreditation body for chemistry graduates in the UK. After an extensive examination of documentation submitted, a team visit last June, subsequent discussions with staff and students and our satisfying their requirements for upgrading our programme, the RSC has now accredited the Graduateship programme as fulfilling partially the academic requirements for the award of **Chartered Chemist** (CChem) status.