Chapter 1
Introduction
1.1 Concept of Controlled Release (CR)

The concept of controlled release technology, emerged actively in nineteen sixties, has attracted wide attention over the last two decades. The research and developmental effects in this area are experienced in medical, agricultural and biotechnological fields (Fan and Singh, 1989). The use of drugs, fertilizers, pesticides and herbicides and similar chemically active agents are inevitable to the modern society. However the extensive and unjudged use of these biologically active chemicals have created great alarm among scientists world-wide, because of its adverse impact on the health and environment. The uncontrolled application of these chemicals almost inevitably induces many undesired side reactions in systems which receive them. Controlled release technology finds its potential use in minimizing or avoiding these 'side reactions' during the course of action of the active agents by a controlled release of them to the system (Paul, 1976; Fan and Singh, 1989).

Several low molecular weight biologically active agents are in use at present. These agents during their action manipulate the environment around and within us. Hence its efficient, safe and economic use is to be strictly followed for sustaining the environment and human health. The conventional use of these chemicals in biosystems, produces peak and valleys of its concentration within the system in a very short period of time. This necessitates repeated application of these agents to the system in order to maintain its concentration level for performing the function. These periodic applications produce maximum and minimum of active agent concentration in the system. Usually these concentration profile involves harmful and ineffective phases. Thus the efficiency of these chemicals relies on its release to their site of action at the right time and in right quantity (Paul, 1976; McCormick, 1987).

Concentration levels of an agricultural chemical or a herbicide in a system, when administered through different modes of conventional (uncontrolled) and controlled manner, are represented in figure 1.1. The upper horizontal line represents the maximum admissible level (MAL) of the herbicide concentration in the system, above which crop damage may takes place, and lower horizontal line represents the
minimum concentration level of the herbicide required in the system for the specified action to takes place. In the uncontrolled application of the herbicide (Curve A), the period of action is very short and a part of applied herbicide is wasted, since that is not available in the system at required level. Usually to overcome this shortfall, herbicides are applied at a higher concentration (Curve B). Here the concentration level of herbicide in the system goes beyond the MAL and this results in crop damage. Though the period of effective action is for a longer time, than in case A, damage of the receiving system as well as wastage of chemicals are there.

![Diagram showing typical herbicide concentration vs time profile for various modes of delivery]

**Fig 1.1.** Typical herbicide concentration vs time profile for various modes of delivery

- A. Conventional method of application
- B. Conventional method (overdose)
- C. Controlled Release method

The CR formulation delivers the herbicide in right amount (Curve C) and period of action is much longer than in cases A or B; and an ideal system can
maintain the optimum level of concentration of herbicide in the system for an entire crop period. Repeated 'B' type application will result in very wide variations in herbicide concentration in the system; sometimes too high, to set in undesired side reactions or too low such that the desired action is not performed. Thus by uncontrolled applications of active agents loss of chemicals and environment pollution due to 'side reactions' take place. Neogi and Allan (1974) had illustrated this with a specific example. A pesticide with a half-life period of 15 days and with dissipation rate of first order and when a minimum level of 1 mg/day is necessary for effective pest control, if applied by conventional method for a period of action of 50, 100 and 150 days require 10, 100 and 1000 mg respectively; but if it is released in a controlled manner by a CR formulation it can maintain the minimum required level of 1 mg by continuous supply to restore the amount dissipated, only 3.3, 5.6 and 7.9 mg would be required. Thus considerable amount of costly chemicals can be saved. The losses due to overdoses, usually taking place in conventional application are also minimized, thereby the environment pollution is checked. Moreover the period of action is prolonged with a bare minimum of chemical in the medium. In the application of any active agent to a biosystem, a desirable regime is to release the active agent in a controlled manner and to maintain an optimum level for the required period (Mc Cormick, 1987).

Controlled Release (CR) technology is widely made use of in drug formulations in fertility control (Flynn et al 1976), narcotic antagonism (Yolles et al 1976), fluoride for dental purposes (Halpern et al 1976), cancer curing (Yolles et al 1976), and cardiac arrhythmia and to induce hypertension (Chien et al 1976). In the agriculture sector several CR formulations of fertilizers, herbicides, pesticides and pheromones had been developed (Beaton et al, 1967; Shasha and Trimnell, 1989; Schacht et al, 1980; Akelah and Moet, 1990; Kyodonieus, 1980). Major advantages of CR techniques are more efficient utilization of the active agent, possibility of targeting, less frequent administration and reduction in side effects (Fan and Singh 1989).
1.2 Polymers in Controlled Release Technology

Polymers, both natural and synthetic, are very much useful in preparing CR formulations. Most of the drugs, fertilizers, herbicides, pesticides and pheromones are low molecular weight compounds. The tremendous progress in polymer science and technology could make it possible to combine a low molecular active agent species physically or chemically to a polymer through a pre- or post- polymerization reaction. In CR technique the active agent is allowed to release from the polymer-active agent combination over a period of time, most often to a specific target. In physical combinations, polymer acts as a rate-controlling device while in chemical combinations it acts as a carrier for the active agent (Akelah and Moet, 1990).

Another important advantage of polymeric CR formulation is that the toxic nature of the chemicals are minimized. Many new pesticides are readily biodegradable and highly toxic. For example the organophosphates are very toxic and due to their mobility in air and water, proper respiratory protection measures are inevitable for the persons handling it. Moreover it poses great danger to non-target organisms also. But if it is encapsulated or distributed in a polymer, its toxicity will be much reduced, since all the amount does not release at one time. Still another advantage is that the polymer combinations being solids are easy to handle (Neogi and Allan, 1974).

The success of CR formulation relies on combining the active agent with the polymer in an economic manner, at the same time maintaining the desired release profile. These are often in opposition and one has to compromise in the ultimate cost/benefit ratio of CR formulations (Paul, 1976). However there are many new classes of polymers which can be effectively employed in CR formulations. The efficiency of CR formulations depends on the following polymer properties:

1) Solubility and distribution characteristics with the active agent.
2) Solubility and distribution characteristics with the environmental agents.
3) Compatibility with the environment. It should be non-toxic.
4) Compatibility with the active agent. It should not produce undesirable products.
5) Stability in the environment. It should not degrade during the course of action.
   Preferable if degraded after the desired function is over. The degraded products
   should not harm the environment.
6) Mechanical properties. It should be in a suitable physical form to be easily administered to the system.
7) Ease of fabrication.
8) Cost.

The sought-after release profile from a CR system is the steady state release of
active agent, or a zero-order release mechanism kinetically. The attraction of such a
system is that the rate of release is not affected by the amount of active agent released
or not released at any moment (Paul, 1976). However, many of the CR formulations
do not fall under this category. Depending on the rate-controlling mechanism
involved, the CR systems can be classified into several classes. According to Fan and
Singh (1989) the major release mechanisms involved in CR formulations are

1) Diffusion
2) Erosion or Chemical reaction controlled.
3) Swelling
4) Osmosis

1) Diffusion - Controlled Systems

Here the rate determining step is the diffusion of active agent through the polymer. The polymer-environment fluid interaction is practically nil, or polymer is seldom affected by the environment factors. Mainly two categories of diffusion-controlled devices are employed in CR formulations.

a) Reservoir Systems

Here the active agent and polymer are physically combined or active agent is
encapsulated in a spherical or cylindrical polymeric device. Micro, macro or nano encapsulation co-acervation and spray encapsulation are well-developed techniques and are employed in drug delivery systems (Speieser, 1976). Active agent releases out to the environment by diffusion, through the micropores of the capsule walls. Ethylene-vinylacetate co-polymers, silicone rubber, polyethylene and polyurethane are commonly used to fabricate such systems (Fan and Singh, 1989).

b) Monolithic systems

Here the active agent is either dispersed heterogeneously or dissolved in the polymer. The polymer can be bio-degradable or non-bio-degradable. The dissolved or dispersed active agent releases out by diffusion. If interaction is possible between polymer and environment fluid, release may takes place by leaching also in addition to diffusion. If a soluble additive is incorporated in the polymer matrix, the environmental fluid can easily penetrate the matrix by dissolving the additive and interconnected channels will be formed, through which the release would be easy. These type of physical combinations need not be influenced by structure of the active agent or polymer. Hence this technique has a general applicability. A wide variety of active agents can be incorporated with a broad range of polymers to prepare CR formulations. Polymer matrix of silicone rubber, ethyl cellulose and hydroxypropyl cellulose are widely used in this category (Akelah and Moet, 1990; Fan and Singh, 1989).

2.a) Erosion- or Chemical Reaction- Controlled Systems

The active agent is physically immobilized in the polymer matrix and release occurs only by the erosion of the polymer. In an ideal system polymer matrix undergo surface erosion, releasing active agent at a rate proportional to the erosion rate. If erosion rate is constant and the matrix dimensions remains unchanged a zero order release rate can be achieved. Poly(vinyl pyrrolidone) and co-polymers of lactic and glycolic acids are used in preparing such systems (Fan and Singh, 1989).
B) Chemical Reaction Controlled -Systems

The active agent is chemically bonded to the polymer either by a covalent or ionic bond. The active agent is incorporated either as a pendant group in the polymer chain or in the polymer backbone itself. Chemical modification of the pre-formed polymer with a desired active agent lead to a polymer with the active group present as a pendant (Fig 1.2). Polymerization of active monomers may lead either to polymers with active agent as repeat units (Fig 1.3) or polymers that contain active agents as pendants. Positively or negatively charged active agents combine with ion exchange resins to form poly salt resinates (Akelah and Moet, 1990). Pendent chain complexes with agricultural and pharmaceutical active agents had been developed (Harris et al, 1976; Duncan and Kopacek, 1984)

\[
\begin{align*}
\text{---(P---)} & \quad \text{---(P---Z---)} \\
\mid & \quad \mid \\
\text{n} & \quad \text{n}
\end{align*}
\]

Fig 1.2 Active agent attached to polymer as a side chain

Fig 1.3 Active agent in the polymer backbone

\( P \) - Monomer unit \( Z \) - Active agent

From these chemical combinations, active agents are released only when the polymer active agent bond is cleaved, otherwise the polymer is to be degraded. When the active agent is a co-monomeric unit in polymer backbone, release may occur by polymer degradation and in such cases the release follow a zero order kinetics (Akelah and Moet, 1990).

3) Swelling CR System

The active agent is dispersed or dissolved in a polymer matrix, in which it is unable to diffuse to any considerable extent. When the polymer gets into contact with an environment fluid which is compatible with it, swelling takes place and the active agent present in the gel portion of the matrix diffuse out. Poly(hydroxy
methylmethacrylate), polyacrylamide and poly(ethylene glycols) are used in such systems (Roorda et al., 1986).

4) **Osmotic Pumping Systems**

In this type of devices the driving force is the osmotic force. Usually such systems consist of a solid and water soluble active agent, which is enclosed by a water-permeable, but active agent-impermeable, polymer membrane with a small opening. Water is transported into the core by permeation and hydrostatic pressure will be built up in the core and subsequently, the dissolved active agent comes out (Fan and Singh, 1989).

Apart from these common techniques, new concepts such as magnetic or ultrasound modulation, viable cell immobilization, microspheres and nano particles and targeted delivery are under thorough research in the CR field (Hsieh and Langer, 1980; Koestler, 1980; Fan and Singh, 1989).

A very wide variety of polymers are utilized in CR technology. Development and innovations in new high-tech class of polymers are one of the primary factors responsible for the very rapid and encouraging development in CR technology, which is not only aiming at preserving the environment but also considering the economic aspects.

1.3 **Polymers as Soil Conditioners**

Creating a suitable soil media is very essential for effective growth of plants. For increasing food production more 'problem soils' (uncultivable soils) are to be made suitable for cultivation. Many soil problems hindering cultivation are tackled to a great extent by the use of soil conditioners. A soil conditioner is defined as any synthetic chemical or chemically modified substance that stabilizes soil aggregates and/or favourably modifies soils’ structural or physical properties. Ferric sulphate, triphenyl sulphonium chloride, portland cement, periodates, phosphoric acid, calcium...
chloride, soap, hexadecanol and various types of polymers are examples (Azzam, 1980; Seybold, 1994).

Several synthetic and natural polymeric soil conditioners are now in use to stabilize soil aggregates and to modify favourably the soil physical properties. They can improve water retention capacity and prevent wind and water erosion. Even about thirty years ago 'Krilium'- hydrolysed polyacrylonitrile was commercialized as a soil conditioner and was reported to improve soil permeability (Seybold, 1994). However its efficiency varied soil to soil (Quastel, 1953). Polystyrene, foam plastics and styromull are insoluble polymers that are used as soil conditioners to convert heavy clayey soils to air permeable and warm one. Bitumen is another material in this class, employed as emulsions for reducing soil run off and saving water in sub soils. This is particularly useful for tropical rainy zones (Azzam, 1980). Polystyrene based macronet polymers are reported to be potential soil conditioners (Kakoulides et al, 1993). Several soluble polymeric soil conditioners are reported to be effective in reclaiming clayey soils. Examples are poly(ethyleneglycols), poly(vinylacetate) and poly(vinylalcohol) (Carr, 1975; Dowdy, 1972 and Azzam, 1980). Natural rubber, ethylene vinylacetate co-polymer and polymethylmethacrylate are also reported to be useful as soil conditioners for various purposes (Soong and Yeoh, 1974; Azzam, 1980).

Polyelectrolytes are the most distinct class among soil conditioners. Several acrylate/acrylamide polymers and co-polymers are very widely used and are reported to be much useful in improving chemical, physical and agronomical properties of soil. Moreover it is very effective in reclaimation of saline and alkaline soils (Allison, 1952;

### 1.4 Polymer - Soil Interactions

The effectiveness of polymers as soil conditioners depends on its ability to interact with soil fractions especially clay. Properties of soil as well as polymer
decides the extent of such interactions. Molecular weight, molecular size, type and amount of surface charge and configuration are the major deciding factors of polymers while the soil factors are the type and amount of clay in soil, ionic strength and type of ions. Also soil pH influence the polymer-soil interactions (Seybold, 1994). The polymer soil ratio also is a very important factor. Adsorption of polymers in soil depends on the type of polymer charge and it decreases in the order cationic > non-ionic > anionic. Non-ionic polymers interacts with clay fraction of soil through Vander Waal's forces. Positively charged polymers are electrostatically adsorbed on negatively charged soil fractions, such as clay or organic matter. Negatively charged polymers get adsorbed to soil through "cation bridges" between polymers and soil anionic groups (Bicerano, 1994; Benhur et al 1992; Letey, 1994).

1.5 Polyacrylamide as Soil Conditioner

Polyacrylamide (PAM) is a water-soluble polymer and is one of the most widely used and extensively studied soil conditioners. Several reviews are available on the preparation and usage of PAM (Azzam, 1980; Seybold, 1994; Barvenik, 1994). It is otherwise widely used as a flocculent in potable/waste water treatment, to strengthen paper, as adhesion and flooding agents in petroleum industry, in gel electrophoresis and in textile and soap industry as a thickening agent (Seybold, 1994).

As a soil conditioner anionic polyacrylamide (20% hydrolysed) has been reported to be most effective in stabilizing soil, since in such a condition the polymer chain is maximum extended facilitating maximum adsorption or interaction with clay (Shainberg et al, 1990; Malik and Letey, 1991). Once absorbed desorption of PAM from soil very rarely takes place (Letey, 1994). Soil with stable aggregates favours water infiltration and acts against wind and water erosion. PAM as per reports is a good soil stabilizer and is useful in stabilizing structureless soil and sand dunes (Azzam, 1980; Wallace et al, 1986; Levy et al, 1992; Shainberg et al, 1992 and Nadler et al, 1996). As per Terry and Nelson (1986) aggregate stability of a soil increased from 17 to 80 % upon PAM application. PAM when applied with suitable
crosslinking agents such as glyoxal is found to be increasing the stability of soil aggregates and prevents soil compaction and increases soil friability (Azzam, 1980).

Water drops of rain or sprinklers can cause detachment of soil particles and enhances their movement. These detached particles clog at the surface of soil and are usually about 1 to 2 mm thick. This seals the soil surface and drastically reduces water infiltration causing higher runoff and further erosion. Surface-sealing and erosion are greatly controlled by PAM. (Seybold, 1994; Stern et al 1992; Fox and Bryan, 1992; Shainberg et al 1990; Zhang and Miller, 1996; Lentz et al, 1992; and Lentz and Sojka, 1994; Wallace and Wallace (c), 1986).

As per reports PAM greatly increased the water infiltration rate of a loess type soil from 2 to 23.5 mm/hour and the rain intake from 12.3 to 64.2 mm in a 80 mm rain. This is very important since soils of semiarid regions are unstable and much loss occurs due to run off in rain storms. PAM is a great promise for such soils (Shainberg et al, 1990 and Azzam, 1980). Smith et al (1990) had reported that an increased erosion and decreased infiltration takes place as the impact energy of rain water drops increased. However an higher infiltration rate and decreased erosion was noticed in PAM applied soil compared to untreated plot. Irrigation efficiency is reported to be much increased when PAM is applied through irrigation water at very low concentration. Water holding capacity of soil is greatly enhanced by the usage of PAM (Terry and Nelson, 1986 and Azzam, 1980).

Growth and yield of many crops are reported to be increased upon PAM application and they include wheat, rice, maize, oats, cereals, barley, cotton, sugarbeets, rye grasses and horse beans (Azzam, 1980 and Stern et al, 1992). Increased dry-matter production and seedlings emergence in tomato, cotton and lettuce upon PAM application were reported by Wallace and Wallace (a & b, 1986). Adequate germination rate was achieved in calcareous silty and sandy loamy soils by PAM treatments. The major reason for these increased growth and yield of crops is due to the improved physical property of the soil and the increased water infiltration and aeration upon PAM application. Delaying dissolution of fertilizers, increasing
sorption capacity or favouring the uptake of some nutrients by plants, enhancing soil microbial growth and imparting friability which results in improved rooting are also reported to be the possible reasons for the increased yield on PAM application as per Azzam (1980) in his extensive review on PAM. He also reports that urea and ammonium sulphate were found to be participating in coagulating soil particles when applied along with PAM and behave like long acting fertilizers.

Large quantities of PAM are intensively used to deal with problem soils. The major reason for the widespread application of PAM in Europe was the successful modification of non-fertile, calcareous land near Dijon in France. About 4% of arable land in Belgium (4000 ha), 5% in France (20,000 ha) and Germany (20,000 ha) are under PAM application. In Indonesia PAM application could reduce soil erosion from 17,000 Kg/ha to 4000 Kg/ha. Water repellency under citrus trees in Egypt also could be alleviated by PAM application. In Belgium, France and Germany PAM is mainly used as a mulch material in silty soil for promoting germination of sugar beets. By spraying 0.2% PAM solution the crop yield could be increased by 8 to 10% (De Boodt, 1975 and Azzam, 1980).

The equatorial and tropical soils which receive very heavy rain due to which the aggregate stability is continuously decreasing and the bulk density increasing. Consequently water intake and storage are reduced and surface run off and erosion greatly increased and heavy doses of fertilizers are required for these type of soils. In situation where heavy doses of fertilizers are required tillage problems becomes difficult, PAM is a potential soil conditioner. By PAM application erosion can be reduced while aggregation, porosity, aeration, friability, infiltration, storage capacity and fertility can be increased, thus making the soil more sustainable and tillage operations made more easy (Azzam, 1980).

In solving food shortage problem, increasing productivity, sustaining the existing arable land and the conversion of 'problem soils' to arable one are very important. PAM-like polymers are helpful in sustaining the soil and environment

Prepared by BeeHive Digital Concepts for Mahatma Gandhi University
(Wallace and Wallace, 1994). The above discussion points out the importance of soil conditioners in solving the problem.

1.6 Fertilizers and Agricultural Production

The importance of fertilizers in agriculture is well understood erstwhile, and present agriculture production greatly depends on it (Cardarelli, 1976; FAO, 1981). It is believed that fertilizers and pesticides are responsible for the 60% of the total agriculture production. Fertilizer consumption and production has increased several folds when compared to the nineteen fifties or sixties (FAO, 1985). Russel et al (1989) had formulated a relationship between world nitrogen fertilizer use on cereals (X) and mean world cereal yield (Y) between 1956 and 1985, which is expressed by an equation $Y = 1202 + 13.3X$ with $R^2 = 0.983$. This clearly indicates the dependence of crop yield on amount of fertilizer applied. Now fertilizers have turned to be one of the costly input in agriculture. Among the N fertilizers, urea is the most widely used one because of its very high N content, ease of handling and comparatively low cost. It was introduced as a fertilizer in 1935, but its global acceptance and extensive use commenced only from early sixties. Now about 70% of the total N fertilizer used in Asia is urea. India also consumes substantial amount of urea every year (in 1994, 17 million tons). However, efficiency of urea in soil as per several reports is very low (Gould et al, 1986; Fertilizer Statistics, 1995; Prasad et al, 1971).

1.7 Urea in Soil

Often fertilizers and other agro-chemicals are applied in amount far excess than the actual requirements. Cardarelli (1976) is of the opinion that only about 15% of the applied fertilizer enters the crops. Harper et al (1983) points out that N losses from applied fertilizer varies from 20% to 80%. Food and Agriculture Organisation (FAO) estimates that 40-70% of the applied fertilizer is lost to the environment (FAO, 1983).
Urea when applied to soil is rapidly hydrolysed to ammonium bicarbonate. This reaction is catalysed by the enzyme 'urease' found in many species of bacteria, fungi and yeast. The ammonium bicarbonate thus produced is subsequently nitrified to nitrite and then to nitrate. The first conversion to nitrite is by the activity of 'nitrosomonas' and the subsequent conversion to nitrate is by the activity of 'nitrobacter' species of microbes (Gould et al, 1986).

The rapid hydrolysis of urea in soil elevates the pH around the urea granules and results in high concentration of ammonium. This situation is very conducive for ammonia volatilization (Gould et al, 1986). One of the major ways of urea loss is by volatilization as ammonia. The ammonia in high concentration in soil is toxic to germinating seeds. Ammonia volatilization is severe when urea is applied by surface broadcast method especially in hot countries (Greenwood, 1981). The loss of urea as ammonia from flooded rice fields poses very serious problems. Biological denitrification is also a major mechanism of N loss from rice fields that are urea fertilized. A considerable amount of applied urea-N is lost in the form of ammonia from agricultural fields (Gould et al 1986; Bohlool et al 1992; Fernando and Roberts, 1975).

Leaching is another mechanism by which loss of urea and other ammonium forming fertilizers takes place. Urea is a non-ionic and highly water soluble compound and is susceptible to leaching. It is weakly absorbed in soil. Leaching losses of urea occurs by two processes. Urea leaches as such, and as nitrate, the converted product of it in soil. Nitrate ions are very mobile in soil and easily leach down (Gould et al, 1986). It is reported that most of the unused nitrogen (that is not taken up by plants) from agricultural fields out of the fertilizer application leaches down to ground water sources and contaminate the canals, rivers and lakes. The nitrate ion contamination in drinking water causes serious concern, as it is a suspected agent causing 'methaemoglobinaemia' in babies and cancer in adults. Maximum admissible concentration (MAC) in drinking water for nitrogen is 11.3 mg/litre as per the direction of European Economic Community. It is reported that the number of
people receiving drinking water outside MAC of nitrate is increasing every year. To solve this problem, one of the suggestions was to eliminate or reduce the use of N fertilizers. If this suggestion is opted and followed, drastic reduction in crop yield will be resulted. The pollution due to nitrate ions in drinking water is often called as a 'chemical time bomb' by water scientists (Hepburn et al, 1987).

Another problem encountered in urea application is nitrite ion accumulation in soil which is toxic to plants and cause losses of nitrogen. It is reported that the alkaline pH and high ammonium concentration due to the urea hydrolysis in soil affects adversely the 'nitrobacter' species, but not the 'nitrosomonas' species of bacteria. Hence the urea to nitrite conversion do take place but subsequent conversion of nitrite to nitrate is inhibited. Due to this nitrite ions accumulate and losses of nitrogen takes place as NO and NO₂. These oxides of nitrogen can cause depletion of the precious ozone layer that protects the earth from radiation hazards. Eutrophication (accumulation of salts) of river estuaries is yet another problem associated with over consumption of urea. This very seriously affects the aquatic biota (Bohlool et al 1992; Sahrawat and Keeney, 1986).

1.8 Scope of the work

The increasing rate of urea production itself is an evidence for its increasing consumption. It is a globally accepted and the most widely used N fertilizer. Prasad (1971) points out, in field studies N recovery of urea and other nitrogen fertilizers is about 50% or below for most of the crops. The other 50 % of soil applied urea and other N fertilizers is simply lost to the environment and creates severe environmental problems as explained earlier. In such situation where an increased food production is a necessity and when that is possible only with the aid of chemical fertilizers like urea, and when serious environment problems arises out of the fertilizer application, it is the major concern of scientific community to increase the efficiency of urea like fertilizers or to minimise the loss of fertilizers to the environment, thus helping the farmers to produce more while sustaining the environment. Ever since the fact that
low fertilizer efficiency of urea was recognised, efforts were made to increase its use efficiency and it is still continuing.

CR technology can offer much to solve this problem. It is evidenced by the past work as well as the suggestions made by several agencies. FAO suggests the fertilizer manufacturers to increase the efficiency of fertilizers by the development of CR fertilizers. Organization for Economic Co-operation and Development had proposed to concentrate research on CR fertilizers to alleviate the nitrate ion problem in drinking water. The Scientific Advisory Committee to Prime Minister of India in their report in 1988 says "while on the subject of fertilizers, it needs to be emphasised that by using modern science and technology inputs a significant amount of conservation is possible. Much of the urea that is applied to the soil is lost due to leaching and nitrification. Controlled Release of urea could offer impressive savings, but we have not provided sufficient S & T inputs in this vital area to make this possible" (Hepburn and Arizal, 1988; Gopakumar et al, 1993).

The physical or chemical combinations of urea with polymers and other materials make it a slow release product and several such formulations are available. The major advantages of such formulations are

1. A metered or slow release of urea to the soil over a period of time is made thereby sustained correction of N deficiency is possible. An increased N uptake by plants results, by which yield is increased. This also reduces the over-consumption of nutrients by crops and a fairly uniform growth of crops is ensured throughout the growing season.

2. As the action of CR fertilizers can be adjusted to sustain for a long time, (better systems can perform the function for the entire crop season) frequency of application can be minimised. Thus less labour cost and less machinery damage to crops results.

3. Losses due to leaching and vaporization are minimized. Thus the use efficiency of urea increases and reduces the environmental pollution considerably (Joyce et al, 1988; Trivedi and Pachayappan, 1979).
Agricultural productivity can not be increased without chemical fertilizers. At the same time fertilizer application should not tamper the environment equilibrium. Controlled Release Technology is very much applicable to this problem. Proven soil conditioners had been utilized in this study to prepare CR urea fertilizers so that CR property and soil conditioning property are tried to be merged in a single product.

The present study aims to incorporate suitable polymer and fertilizer urea in such a manner that the product have CR property. The selection of polymer was very important since the properties of which is the deciding factor of the CR property of the product. Crosslinked polyacrylamide / polymethylmethacrylate were used for coating urea in the present study. Along with these, the suitability of polymers like polystyrene, poly(vinylchloride), ethylene vinylacetate co-polymer and natural rubber to be used as sealant materials for the coating were evaluated.