Chapter 2

Review on Polymer-Based Controlled Release Agro-chemicals
2.1 Polymers in Controlled Release Agro-chemicals

The different classes of polymers viz. elastomers, plastics and fibers are extensively used in agriculture for varied purposes. The major application fields include CR pesticides, herbicides and fertilizers, soil conditioning, plant protection, seed coating and gel planting (Mc Cormick, 1984). A number of CR agricultural chemicals had been successfully tested and are commercially available. A detailed list of synthetic and natural polymers used for the preparation of such formulations are given by Kyodonieus (1980). Controlled Release agricultural chemicals other than fertilizers are discussed initially.

Crops and livestock are produced in a hostile environment comprising approximately of 50,000 species of fungi, 30,000 species of competing weeds and over 10,000 species of insects, in addition to the grain devouring birds and rodents (Cardarelli, 1976). The biologically active chemicals have been very effective in suppressing the undesirable weeds and insects, thereby in an increased food production. However the use of such chemicals should not create any adverse effect on man and his environment. For example use of DDT, a pesticide with very long life is undesirable since its residue enters the food chain. On the other hand pesticides with very short lives do not serve the purpose. Moreover these materials are susceptible to leaching by rain water, removal by evaporation or by rapid biodegradation into inactive components. These lost chemicals contaminate the ground water and are a threat to aquatic and wild life. In such cases large excess of these costly active chemicals are applied grossly to compensate the losses. In situation like this the CR technology can offer much to save the costly chemical and the environment, more over the desired action can be prolonged. Many of the active biological agents are effective at very low concentrations. Different CR formulations having varied release profile had been synthesized by incorporating these chemicals either physically or chemically to polymers (Cardarelli, 1976; Neogi and Allan, 1974).
2.2 Physical Combinations of Polymers and Active agents

The pre-requisite of a CR physical combination is that the polymer and active agent should not unnecessarily react. Several physical combinations of polymer-pesticide and polymer-herbicide are commercially available and many are under experimental stage (Cardarelli, 1980 a). For CR formulations plastics are preferred to elastomers due to its comparatively low cost and ease of processability. The solubility of an active agent in plastics is difficult due to the strong interchain forces. Consequently a diffusion-dissolution mode of agent release is rather difficult to achieve. A major factor affecting release is porosity or free volumes within the matrix of the plastic material, the magnitude of which is controlled by the processing conditions and incorporated additives (Rogers, 1977).

Several pesticides like sevin, dimethoate, ethyl trithion, methyl trithion, diazinon, malathion, chloropyriphos and temephos can be incorporated in plasticized poly(vinylchloride) to obtain CR products (Cardarelli, 1980 a). Chloropyriphos can be combined with polyethylene which can control mosquito larvae for about 18 months by one application itself (Miller et al, 1973). Tributyl tin fluoride in a polythene modified ethylene vinylacetate co-polymer is used as a CR molluscicide (Cardarelli, 1980 a). Polythene-paraffin mixture combined with insecticide 'dichlorvos' has long term effective vapour release (Bogard, 1975). It has been reported that active release is possible for over 160 days when 2,3,6 trichloro phenyl acetic acid combined with polyethylene (Harris, 1973).

Antifouling agents like trialkyl and triaryl organo tin compounds can be incorporated in a variety of elastomers like natural rubber, styrene butadiene co-polymers, ethylene-propylene-diene terpolymers, polyacrylonitriles, polyisobutylenes and polyurethanes. Several organo phosphates, halogenated hydrocarbons and carbamates can be incorporated with elastomers. Temephos/ethylene propylene diene combination had been reported to be a very effective CR pesticide against mosquito larvae (Cardarelli, 1980, b). As early as in 1969, a natural rubber based herbicide formulation containing butoxy ethanol amine ester of 2,4 dichloro phenoxyacetic acid
was developed and found effective against aquatic weeds (Cardarelli, 1980; Thompson, 1974).

Apart from the distribution or dissolution of active agents in polymer matrix, there are other methods like micro or macro encapsulation of active agents using polymers for the preparation of CR products. Interfacial polymerization is the widely used technique for microencapsulation. This method is rather attractive, both operationally and economically since water is the continuous and storage phase. Condensation polymerization reactions yielding polyamide, polyester, polyurea, polyurethane, polycarbonate and polysulfonamide can be very well utilized to prepare CR formulations. In such cases the active agents are dissolved in the oil phase along with monomeric species. Crosslinking of the polymer wall yields durable and storage stable capsules (Lowell et al., 1977; Koestler, 1980). An encapsulated pesticide methyl parathion in crosslinked polyamide-polyurea is marketed under the trade name ‘Penncap-M’. Microencapsulated pesticides like ethyl parathion and diazinon are under field evaluation. Several controlled release pheromone formulations are also synthesized by microencapsulation. Pheromones are highly expensive and volatile and are used to disrupt the mating activities of insects, thus preventing from the insect population build up (Beroza et al., 1973; Carde et al., 1975). Much research is continuing in the utilisation of starch to be used as a polymer matrix for CR agro-chemical (Shasha, 1980).

2.3 Chemical Combinations of Polymers and Active agents

The active agent is chemically attached to the polymer through a covalent or ionic bond. Bio-degradable and non-bio-degradable polymers can be utilised to prepare such combinations. Essentially the biocide and the polymer should contain functional groups which are reactive to each other. The substrate-biocide bond should be such that it may be cleaved by the environmental processes more readily than any other bond in the active agent. Amide, ester and anhydride linkages are very
successfully utilised in CR combinations and systems with high percentage of the active agent can be prepared by this method (Allan et al., 1980; Harris, 1980).

### 2.3.1 Bio-degradable Systems

Biocides having carboxylic acid groups (such as phenoxy carboxylic acids) and the natural polymers having a number of hydroxyl groups such as cellulose, chitin, lignin, starch, alginic acid and lignocellulose had been successfully combined to prepare CR formulations. Heating carboxylic acid herbicides to their melting point and allowing to react with natural polymers yield covalently condensed CR products (Allan et al., 1980). Combinations of phenoxy herbicide acids with natural polymer, aminopolysaccharide chitosan (fish waste) having reactive amine and carboxylic acid groups is an example for amide linkages in CR formulations. CR herbicides by the combination of 3, 6-dichloro-o-anisic acid and fish waste were found to be five times more effective than the free herbicide (Allan et al., 1980). Chitosan is a promising natural polymer for the CR formulations (Allan et al., 1978). Polysaccharides like cellulose, chitin, amylose and amylopectin were found to be useful natural polymers for the CR formulations of 2,4-dichlorophenoxyacetic acid and metribuzin (McCormick et al., 1981). CR formulation of kraft lignin and propachlor have been successfully prepared by Wilkins and Blackmore (1987). Similarly it is reported that rice husk lignin can be combined with 2,4-dichlorophenoxyacetic acid (Kenawy et al., 1992). A review on application of lignin in CR formulations is given by Wilkins (1983). Chemical combination of 2,4-dichlorophenoxyacetic acid and corn starch is also an example of such formulation (Kenawy et al., 1992).

### 2.3.2 Polymers with Pendant Substituents

Two different synthetic methods are followed in formulating such systems. One method is the polymerization of the active agent containing monomers. The other is functionalization of a pre-formed polymer, thereby the active agent is attached to the polymer system (Harris, 1980; Mathew and Pillai, 1993).
2.3.3 CR Formulations by Polymerization of Functional Monomers

The biocides containing reactive functional groups such as carboxyl (-COOH), hydroxyl (-OH), sulfhydryl (-SH) and amino (-NH2) groups can be converted to polymerisable derivatives (Harris, 1980). For example vinyl derivatives of pesticides having carboxyl acid group can be easily prepared by mercuric acetate-sulphuric acid catalysed reaction of the acid with vinyl acetate. Here the acidic H of pesticide is replaced by the vinyl group of acetate (Feld et al, 1975; Harris and Post (a & b), 1975).

Similarly, polymerisable derivatives of pesticides containing acid groups can be prepared by a reaction with alcohols having a vinyl group (Harris and Post, 1974; Harris, 1980). Such functional biocide monomers can be polymerized by bulk, solution or emulsion methods. The vinyl ester of 2,4-dichlorophenoxy acetic acid can be bulk polymerized using free radical initiator azo-bis-isobutyronitrile (AIBN). Solution polymerization method is employed to prepare the co-polymer of 2-acryloxyethyl 2,4-dichlorophenoxy acetic acid and methacrylic acid. Emulsion polymerization is also employed to prepare high molecular weight species of 2,4 dichlorophenoxy acetate (Harris, 1980; Wilkins, 1976).

Co-polymerization of herbicidal monomers and hydrophilic co-monomers were also reported. Co-polymer of vinyl 2,4 dichlorophenoxy acetate and trimethyl amine methacrylamide is an example. Increased release of herbicide is obtained as the hydrophilic co-monomer content increased.(Kenawy et al, 1992; Harris et al, 1976).

Crosslinked polymers synthesized using pentaerythritol triacrylate as crosslinking agent when used in CR formulations showed an almost constant release rate. Acrylate, methacrylate and acrylamide derivatives of the herbicide, biguanide, are also reported and methacrylate and acrylamide species are more resistant towards hydrolysis than acrylate species. It is possible to synthesize covalently or non-covalently bound biguanide systems to various crosslinked polyacrylamide films, having different release profile (Kenawy et al, 1992).
2.3.4 **CR Formulations by Functionalization of Pre-formed Polymers**

Functionalization of pre-formed polymers can also be employed to formulate CR products. By this method a pre-formed polymer is modified to contain the active biocide species. Essentially the polymer and the biocide species should have reactive functional groups. As in the polymerization of biocide monomers, hydroxyl and carboxyl groups containing polymers and biocides are easily combined by this method.

Pesticides containing acid groups are converted to more reactive acid chlorides, which can react with polymers containing pendant hydroxyl or amino groups. Acylation of synthetic and natural polymers are possible in this manner (Neogi, 1970; Wilkins, 1976; Allan et al, 1971 and Allan et al, 1977). In a similar manner pesticides having hydroxyl groups can react with polymers containing pendant acid chlorides. Several synthetic polymers are reported to be prepared by this type of esterification (Harris, 1980). Polymers having pendant hydroxyl groups are also reported to be reactive towards pesticides having reactive aldehyde group (Schacht et al, 1977).

Certain molluscicides are now prepared in combination with polymers to obtain CR products. In such systems an "attractant" can also be incorporated, so that snails are attracted by the genus specific 'attractant' and will be perished, due to the action of toxicant. Copper(II) is very effective against snails and its efficiency is reported to be increased when incorporated with an ion exchange resin as a substrate to hold it. Copper sulphate can be incorporated with styrene-butadiene rubber also and is found to be effective against shistostomiasis (Kenawy et al, 1992).

Some marine organisms continuously settle on the submerged surface of hulls of ships, submarines and buoys and this fouling creates very serious problems including reduced speed, increased fuel consumption and destroy the anticorrosive coating. Conventional biocides application against fouling is effective only for a short period. Several organo metallic polymers that have CR properties are found to be
effective against fouling. Hydrophilic co-polymers consisting of 8-quinolinyl acrylate and acrylamide for the same purpose had been synthesised (Kenawy et al, 1992).

2.4 Controlled Release Fertilizers

An ideal fertilizer supplies the nutrient required for optimum plant growth during the entire growing season and has reasonable cost/benefit ratio and minimum adverse effect on environment (Gandeza et al, 1991). Three widely accepted practices in order to enhance the efficiency of N fertilizers are (a) employing slow or CR fertilizers (b) following cultural practices such as deep placement and incorporation of fertilizers with soil (c) inhibition of microbial activity to minimize conversion of ammonium ions to nitrate ions and/or urea to ammonium ions. Slow or CR is a newer method and formulation of ideal fertilizers based on this technology has been attempted by many research groups.

Slow or CR property for fertilizers is achieved mainly by two methods: (1) Coating or encapsulating the fertilizer in water insoluble or sparingly soluble and inert materials. (2) Synthesizing fertilizer with slow dissolution as in the case of condensing urea with various aldehydes (Beaton et al, 1967; Prasad et al, 1971). Several polymers of synthetic and natural origin and many inorganic substances have been found useful for coating fertilizers (Gandeza et al, 1991; Yeoh and Soong, 1977; Hepburn and Arizal, 1988; Srivastava and Bhowmik, 1976). Release of fertilizers from these coated granules is mainly associated with one or more of the following mechanisms such as (a) water vapour entering the core dissolving the fertilizer and coating bursts due to internal osmotic pressure build up. (b) degradation of coating by microbes or other environment agents and subsequent penetration of water in to the core through the degraded portion, dissolution of the fertilizer and subsequent emission. (c) movement of water to the inner core, dissolution of fertilizer and subsequent evolution of the solution to outside controlled by micropores of the coating. Disadvantage of the first two mechanisms is that once the coating membrane bursts or degrades fertilizer release will be very fast. The third mechanism is very much useful in slowing down the release of fertilizers as water enter to, the core
through tiny pores and subsequently fertilizer comes out to the soil. Here the rate of
release is rather steady comparing to other types and in some case the rate is found to
be gradually declining. Usually temperature influences the rate of release of such
systems. As temperature increases pressure builds up in the core, subsequent release
also is accelerated. However this is beneficial for the plants, since as temperature in-
creases, plant absorption of nutrient also increases. Thus the system can adjust
somewhat the available nutrient in soil as per the plant requirement. In such type of
systems usually the release is independent of pH and microbial activity. Several mate-
rials are used for such coating. Resin, plastic, lac, silica, sulphur, natural rubber,
polyolefin, starch and gypsum were reported to be used for preparing CR urea
fertilizers (Prasad et al, 1971; Chatzoudis and Valkanas, 1995; Brown et al, 1966;
Ahmad et al, 1963; Dhanke et al 1963; Kyodonieus, 1980; Shasha, 1980; Gandeza,

One of the first commercialized and extensively studied slow release fertili-
ers is sulphur-coated urea (SCU). Urea granules uniformly coated with sulphur
followed by a wax coating to seal any pores or cracks of the first coating is found to
have slow release property. The efficiency of the product depends on size of the urea
prill or granules and the thickness of coating (Trivedi and Pachaiyyappan, 1979).

The release from SCU has been reported to take place by one or more of the
following mechanisms. (1) Bio-degradation of either wax or sulphur or both coatings.
(2) Conversion of amorphous polymer sulphur to crystalline form results in the
creation of cracks and pores in the coating. To reduce the microbial attack on coating
sometimes microbicidal agents like coal tar is added. Environmental parameters like
temperature and moisture can also influence the release rate. Other parameters which
affect the release rate are thickness of coating, placement of the granule and time of
contact with soil (Allen et al, 1971; Prasad et al 1971; Gould et al, 1986). There are
several reports on the field performance of SCU. It is found to be very effective for
turf and forage grasses (Allen et al, 1971; Gould et al, 1986). It is reported that when
high amount of uncoated urea is supplied to burmuda grass turf, it merely destroyed
the turf, whereas ammonium nitrate caused moderate burning of the foliage while SCU caused no damage. Similarly application of uncoated urea at 112 kg/ha to corn seedlings, destroyed it while SCU at the same rate caused no damage (Prasad et al, 1971). SCU is also reported to be an excellent N source for ornamental plants in pots. Experiments on corn indicated that on sandy-loam and loam soils where irrigation practices were carefully adjusted to prevent leaching losses, corn yield and N recovery with a single application of SCU was on par with three split applications of uncoated urea (Prasad et al, 1971). Single application of SCU resulted in more yield and more evenly distributed forage and protein than due to three split applications of ammonium nitrate and nitric phosphate. Observations were similar in crops like sugar cane, citrus and rice (Gould et al, 1986).

The major disadvantages of SCU are (1) the sulphur coating, as not very abrasion resistant may crack during shipment. (2) Sulphur oxidising organisms metabolizes S to produce sulphuric acid, hence soil acidification may take place. (3) Inclusion of biocide in wax coating is necessary, otherwise rapid microbial attack on the sulphur coating occurs and results in fast dissolution of urea. However, this enhances the cost further. (4) In countries like India where sulphur is being imported, the manufacture of SCU is difficult.

2.5 Controlled Release Fertilizers Based on Polymers

Plastics as well as elastomers were used to prepare CR urea fertilizers. Urea is either coated with polymer or distributed in a polymer matrix. Polyethylene, polystyrene, ethylene-propylene co-polymer, ethylene-vinyl acetate co-polymer, natural rubber and starch have been successfully used for the formulation of CR urea fertilizers (Brown et al, 1966; Ahmed et al, 1963; Gandeza et al 1991; Hepburn et al, 1987, Savant et al, 1983). As early as in nineteen sixties the concept of CR was tried and practised in the fertilizer field. Dhanke et al (1963) reported that placing fertilizers in polyethylene capsules effectively controlled the release of fertilizers.
Korean Advanced Institute of Science and Technology in collaboration with International Fertilizer Development Centre, had developed several batches of Silicate and Polymer Coated Urea (SPCU) and they had observed satisfactory results for their product on rice (Savant et al., 1983). Their coating procedure involved coating urea granules initially with sodium silicate and then with a polymer latex using fluidised bed technique. Three types of SPCU were prepared with high, medium and slow release rates. The dissolution rate was adjusted by varying the thickness of coating. The polymer latex used for coating was prepared with styrene, ethylhexyl acrylate and acrylic acid. The SPCU granules retained 2 - 10% of urea two months after application in soil, and this portion of N will be available to plants only after the maximum N requirement stage is over. Nitrogen losses due to NH₃ volatilization, leaching and denitrification is lower for SPCU and it is reported to be superior to uncoated urea (Savant et al., 1983).

An experimental fertilizer called Reactive Layer Coated Urea (RLCU) had been developed by International fertilizer development centre (Christianson, 1988). Coating procedure involves placement of urea granules in a rotating drum, heating and spraying with diphenyl methane diisocyanate. This reacts with NH₂ groups of urea and forms a 'reactive layer coating' which have excess unreacted NCO groups. On this coating hot aromatic polyester polyol was sprayed and allowed to react with the free NCO groups to form a water insoluble sealing layer. Uniformly sized urea granules were taken for the process, thus regulated the thickness of coating to obtain relatively uniform product. The material was yellow in colour and was free flowing. The coating was reported to be hard and abrasion resistant. The rate of release was affected by coating thickness, temperature and to a lesser extent by soil moisture. As coating thickness increased, rate of release decreased. The mechanism of urea release from RLCU is reported to be by the movement of water vapour through the coating, because of the high osmotic gradient existing between the fertilizer and soil due to the high humidity in soil. The water vapour dissolves the urea in RLCU and comes out by diffusion. It is also reported that soil pH and microbial activity were not influencing the release rate of RLCU (Christianson, 1988).
Polyolefin-coated urea fertilizer (POCU) was developed in Japan (Gandeza et al 1991). Several types of POCU with varying release rates are reported to be commercially available in Japan. The coating is primarily a blend of polyolefin type resin, ethylene vinylacetate co-polymer and polyvinylidene chloride as major components. Moisture permeability of this resin coating depended on temperature and this property is reported to be achieved by incorporation of inorganic fine powder of talc, silica and metal oxides with the polymer coating. By varying resin/talc ratio different products with different dissolution rate could be obtained. The release mechanism of this product involves movement of water into the granule by osmotic potential, dissolution of urea and diffusion of urea solution through the coating. Release primarily dependent on temperature. For every 10°C rise in temperature, N dissolution from the granules doubled. POCU is considered as a CR nitrogen fertilizer since N release is controlled by the moisture permeability of the coating which in turn is controlled by temperature. Release was reported to be less sensitive to soil pH and soil moisture. (Gandeza et al, 1991).

Starch, natural rubber and poly ethylene vinylacetate have been used as a matrix for the preparation of CR fertilizers either by dissolution and/or distribution. Otey et al (1984) describes the preparation of starch-urea blends. The method yielded granular products with comparatively higher rates of release and will be useful for crops which needs N at a faster rate. Natural rubber had been used to produce slow release fertilizers by Yeoh and Soong (1977). Their method of preparation involved blending of nitrogen, phosphorous, potassium and magnesium fertilizers with natural rubber solution in toluene and extruding fertilizer-rubber blends and cutting to small pieces after drying by passing hot air. These granules were coated first with a rubber solution and then with a combination of rubber solution and pre-vulcanized concentrated latex. In order to enhance drying they had incorporated propylene glycol with the latex concentrate. To avoid sticking together, small amounts of clay was added to the coated fertilizer. Rubber solution was preferred to latex in preparing the blend since high concentration of fertilizer salts coagulated in the latex which resulted in non-uniform dissolution of fertilizers. This encapsulated fertilizer released nutrients
gradually and more evenly and better growth was obtained for rubber plants, compared to the conventional fertilizers. Coated fertilizers with thicker coating were less hygroscopic and had lower release rate. This fertilizer was reported to be suitable for sandy soils were nutrient retention is low and leaching problems are maximum (Yeoh and Soong, 1977; Soong et al, 1977).

Another natural rubber based slow release fertilizer had been formulated by Hepburn et al (1987). Here instead of coating fertilizer granules with polymer, it is distributed in a polymer matrix (natural rubber). The advantage of a flexible matrix is that it is less vulnerable to excessive impact of abrasion during shipment and handling. Rubber was cold masticated and then activators, accelerators and sulphur were added. Afterwards urea was added along with processing aid-urea sealant and dispersed in the matrix. Polyethylene plastic waste / an aromatic oil (dutrex 729) / oleic acid / microcrystalline wax / additional masticated rubber were used as processing aid cum urea sealants. It is reported that the crosslinking influences the rate of release of fertilizer from the matrix. The crosslinking process was aided by zinc oxide, stearic acid, tetra ethyl diuram disulphide and 2. mercapto benzthiazole. For easier incorporation of urea in rubber at higher temperatures, microcrystalline wax was found to be useful. They had evaluated the product by leaching experiments and found that as urea content of the product increased rate of release also increased. The processing aids at concentration of 10 % or below increased the rate of release and at higher concentrations the rate of release was comparatively low. The dissolution rate of this product is influenced by temperature positively. However, some problems regarding the processing are still existing to be refined. The Urea -Rubber Matrices (URM) even at higher application rates like 500 Kg/ha did not adversely affect the seed germination while prilled urea at 300 Kg/ha itself affected severely the seed germination. The release of urea from URM was mainly by diffusion. The microbial decay of rubber matrices was also reported to be a factor involved in dissolution mechanism. Another factor affected release of urea was root penetration of the URM (Hepburn and Arizal, 1988; Hassan et al, 1990; Hepburn and Arizal, 1987).
Several naturally occurring materials were also found to be effective in coating fertilizers. Lac and gypsum are such materials. Srivastava and Bhowmik (1976) had made use of shellac for coating fertilizer urea. As shellac absorbs moisture due to the presence of five hydroxyl groups in its molecule they had reacted it with rosin, so that four hydroxyl groups were esterified and used for coating urea. Urea granules were made moisture free and tumbled with linseed oil. To the oil smeared hot urea granules resin powder was added. The resin melted and spreads over the granules. Recoating was done with oil and resin powder by the same procedure. Soap stone powder was used as a conditioner. A third coating again with the oil and resin powder was done. To this three times coated urea, coal tar as a microbicide was added and tumbled. Thereafter a final coat using paraffin wax was done to seal all cracks, pores and uncovered portions of urea granules during the resin coatings. The product was reported to be free flowing and dry and uniformly coated.

As the price of rosin rose up another method of coating using lac alone was reported by Bhowmik (1980). Here ‘Kirilac’ a by-product of lac industry which is of no commercial value was utilized. Kirilac an insoluble mass is formed by the reaction between hydroxyl and carboxyl groups of shellac molecules during its manufacture.

Another coated fertilizer, gypsum coated urea had been reported by Jayalekshmi Aiyar (1989). Urea and finely powdered gypsum were mixed in a pan and water sprayed to the mixture. By adjusting temperature and moisture a uniform coating was obtained. Thereafter a binding agent which polymerize on contact with gypsum was sprayed on to the granules, thus converting gypsum coating to a hard shell. Ammonia volatilization losses from gypsum coated urea was lower than prilled urea. Gypsum contains sulphur and calcium, that are important plant nutrients, is reported to be a potential agent for coating fertilizers.

Controlled release zinc fertilizers had been formulated by Joyce et al (1988). Here the zinc fertilizers were distributed in a polymer matrix and extruded. Ethylene vinyl acetate (EVA) and low density polyethylene (LDPE) and their blends were used as the polymer matrix.
Another approach of making CR fertilizers is to use water absorbing polymers as a carrier for fertilizer solutions. Smith and Harrison (1991) had carried out experiments on acrylate, vinyl alcohol and starch based polymers that can be expanded in fertilizer solutions. Apart from the above mentioned examples of controlled or slow release fertilizers a number of potential patented products are there. This brief review brings out the major development occurred in the field of CR fertilizers over the past few decades. World-wide the importance of CR chemicals especially fertilizers is felt and it is a thrust area of research. However commercialized products are very few due to several reasons, including the cost factor. Hence efforts are being continued by several groups in this field.

An agriculture based economy prevailing nation, India, now having the second largest population in the world has to produce more food and fiber for which application of fertilizers is a must. The high cost and environmental problems associated with application of fertilizers at very high rates makes it justifiable to continue research on CR fertilizers as pointed out by the Scientific Advisory Committee to the Prime Minister of India.

In India urea is produced and consumed in very large quantities. 'Surface broadcasting' method is followed in most of the cases hence losses are very high. Our effort was to evolve suitable systems that can regulate the dissolution of urea to soil, thereby increasing the efficiency and minimizing the pollution. The polymers that are used are proven soil conditioners, it will be useful for generating favourable soil physical condition for better plant growth.