

Chapter 2

Polymers in Plantation and Plants Protection

This chapter is devoted to polymers employed in agricultural applications for various purposes in growing crops and in plant protection. It is divided into four parts: the first part is concerned with the utility of polymeric materials in suitable media for enhancing crop growth under poor weather conditions and to minimize water and nutrient requirements of plants. The second part covers the various aspects of effective utilization of polymeric materials in plant protection against poor weather conditions and birds to increase crop yield, and shortening the crop season. The third part discusses the utilization of polymeric materials as engineering structural components in farm building constructions and machinery and other engineering tools. The fourth part is devoted to the use of polymers in farm water handling and the management of irrigation to control water distribution and conservation.

2.1 Polymers in Plantations

Polymeric materials are extensively used in agriculture for improving the mechanization of farming and growing crops, to enhance the cultivation of plants under adverse weather conditions, and for effecting more favorable conditions for plant development. They are used in agricultural plantations in steadily increasing amounts to obtain higher yields of harvests and for improving the quality of plants in a shorter time and using less space at lower costs [1, 2]. Polymers are used in such agricultural applications as soil conditioners, planting and transplanting gels, seed coatings for controlled germination, soil aerators, and in soil sterilization.

Polymers can benefit plants in the various stages of development: germination, growth, evapotranspiration, flowering, and fruit formation. Their successful application in agricultural plantations includes more rational plant spacing and improved economization, especially regarding plant containers, films for soil sterilization, and as coverings and sheetings for protective structures. They are employed in mulching and as low tunnels, windbreaks, and protective nets; as protective structures in

greenhouses where an artificial microclimate can be precisely controlled. Conventional cultivation schemes are now being superseded by soilless culture on an extensive scale, which now makes use of gullies formed from plastics with the nutrient solutions being circulated through plastics pipes and applied directly to the root system [3–7].

2.1.1 Soil Conditioners

Soil management is aimed at effectively maintaining or increasing agriculture production for the benefit of society and preserving or improving the environment.

Soil factors include soil type, thickness, compaction of soil layers, and ground water conditions. Soil provides a medium to support plants, and is a reservoir for water and plant chemical nutrients made up of a mixture of solids, liquids, and gaseous materials. The solid materials of agriculturally productive soils are variable mixtures of mineral particles (95 %) and organic matter (5 % of animal, plant, fungal, and bacterial origin), capable of supporting plant life and determining the soil type. The mineral portion contains particles differing in size, shape, and chemical composition, and is the final product of the weathering action of physical, chemical, and biological processes on Earth. The liquid portion of the soil consists of water that fills part or all of the spaces between solid particles. It is crucial because it contains nutrients that plants need for growth and survival, some of which have entered through the soil surface. The remaining pore space between the soil particles that is not filled with water is occupied by air. The topsoil is the top layer with maximum biological activity and contains most of the organic matters. The subsoil receives organic matter, nutrients, and clay particles through leaching from the topsoil. Soils exhibit a large variety of characteristics that are used for their classification for various purposes. Soil characteristics include: strength, soil particle size, permeability, degree of maturity, and soil composition. Soil texture is classified according to increasing particle size into: clay, silt, sand, gravel, and rock. The voids between the larger particles are entirely filled by smaller particles, i.e., sand fills the space between particles of gravel, silt between particles of sand, clay between particles of silt. The finer grained soil particles, silt and clay, are powdery, hard, and impenetrable in the dry condition, but exhibit spongy and slippery characteristics when wet and become fluid when mixed with water. It is difficult to find a soil that is in perfect physical condition for agriculture plantation purposes. Humid *tropical soils* exposed to heavy rain intensities suffer from the decrease in aggregate stability and increase in bulk density. Consequently, water intake and storage are reduced while surface drainage and laminar erosion increase. Tillage operation in these soils is difficult and retaining the soil around the growing plants is almost impossible. In *sandy soils*, low water-holding capacities and high infiltration rates are the major problems in establishing a successful plants irrigation system. In *clayey soils*, crust formations cause problems for seedling emergence. Thus, there is a great interest in soil reclamation to overcome these problems.

Polymeric materials are being added to soils for reclamation and to improve soil composition and structure. These polymeric materials improve the soil grain structure by forming cloddy soil suitable for vegetation for improving plant growth [8–26]. They reduce water demand especially in sandy soils via increase of water-holding capacity, reduction of water stress, preventing soil erosion by altering soil mechanical structure, improving friability, enhancing the establishment of seedlings, and increasing crop yields [20].

2.1.1.1 Soil Conditioner Types

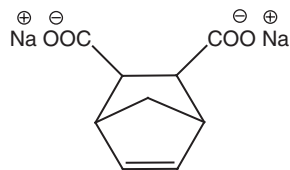
There are various natural and synthetic materials used for soil reclamation. They are added to the soil surface or around the seedling roots at the time of planting, thereby improving the soil's physical properties [21].

- (A) **Natural organic matter.** Animal manure, crop residues, organic compost, sawdust, and various other materials such as food, textile, and paper processing wastes are used for soil reclamation to increase infiltration and retention, promote aggregation, provide substrate for biological activity, improve aeration, reduce soil strength, and resist compaction and crusting, and surface sealing. These are particularly important for improving the crop-growing potential of sandy soils. The use of these materials for the purpose of soil improvement also contributes positively to solving the problem of waste materials disposal from the full range of human activities.
- (B) **Mineral materials.** These can modify the chemical or physical characteristics of soils by increasing soil base saturation (reducing soil exchangeable sodium percentage), increasing flocculation of primary particles and stabilizing aggregates, and reducing dispersion and sealing. In *saline soils*, calcium sources are applied to reduce water sodium adsorption ratio and soil exchangeable sodium percentage. They are important for management of *arid* or *tropical soils* where high temperatures promote rapid bio-oxidation of incorporated organic material. Iron oxides have been used to promote aggregation in soils with low organic matter [27–29]. Inorganic materials such as modified silica are used as soil conditioners for improving soil properties [22–26].
- (C) **Synthetic polymeric materials.** These are designed to produce specific physical and chemical effects in soils for improved agricultural performance; only very small amounts of material are added [30–36]. The mode of action of these synthetic amendment materials can be targeted to a particular physical property of the soil: (1) *Surfactants* affect the surface tension of soils to water and are most commonly used to enhance the wetting and infiltration of treated soils. (2) *Flocculants* enhance the cohesive attraction among dispersed fine particulates and lead to formation of aggregates (flocs) in aqueous media that achieve sufficient size and weight. These materials enhance the existing structural stability of the soil and increase shear strength and reduce detachment.

There are three major classes of synthetic polymeric materials used as soil conditioners to improve agricultural production:

- (a) **Water-soluble polymers** are linear soluble hydrophilic or ionic polymers used as wetting agents leading to more effective water-holding capacity and more stable soil aggregates [37]. The most commonly used water-soluble synthetic polymers effective in soil reclamation especially of sandy soils, include: PEG [38], PVA [39–56], CMC, H-PVAc [57, 58], H-PAN, PiBMA, NaPAA, PVAcMA [33, 59], and water-soluble PAAM [60]. PVAcMA and H-PAN are used for preventing soil surface crusting [61] and for moisture retention [62]. Polyelectrolytes improve the chemical, physical, bacteriological, and agronomical aspects of soils aside from supporting reclamation of saline and alkaline soils [63–65]. Linear PAAM and cationic guar derivatives (polysaccharides) have been applied in sprinkler irrigation water to sandy soils to maintain stability, infiltration, and preventing surface crusting [66]. However, the use of water-soluble polymers in reclamation of clayey soils reduces root growth of plants as a result of inadequate aeration.
- (b) **Hydrogels** are insoluble crosslinked hydrophilic polymers and have the ability to hold water many times their own weight depending on their structures, i.e., water-absorbent polymers, and have the ability to release the absorbed water as the environment becomes dry. Polymers aggregate in different states: solution, gel, viscoelastic, and glassy-crystalline states. The macromolecular solution state depends on the coil density and is characterized by the absence of the physical interaction between the macromolecule chains, i.e., they do not form secondary valence bonds between the chains, but form secondary valence bonds between chains and solvent. As the solvent is removed, the dilute solution changes to a gel in which the chain segments of the coils penetrate each other, i.e., become entangled. The gel state represents a transition between the solution and the solid states. The gel state can be distinguished from the solution state by the fact that the coils no longer move as units or interchange their positions. A general characteristic of gels is their swelling power (the amount of solvent in cubic centimeters taken up by 1 g of crosslinked polymer), which is an indication of the effective pore diameter.

Hydrogels are classified in two categories with respect to the nature of linkages between the coils: (i) the *physical gel* which occurs through secondary valences and undergoes reversible gelation by externally induced topological interaction of polymer chains, either in the melt or in solution. The linkage caused by secondary valences is not of long duration and requires a certain minimum size of the macromolecule to ensure a gel formation upon solvation. Depending upon the differences in the strength of intermolecular forces, there are polymer systems which have either weak or strong tendency to form secondary valence gels. The secondary valence gels usually become liquid again on warming, i.e., they are thermoreversible, and the physical entanglement networks dissolve to form a polymer solution.

Fig. 2.1 Sodium humate

The formation of weak secondary valence gels occurs in poor solvents, which will not prevent all secondary valence bonds between the polymer coils by solvation. The solvation equilibrium is temperature dependent, i.e., it increases at higher temperatures. (ii) The *chemical gel* is a network structure (crosslinked) formed by covalent links between polymer chains. Chemically crosslinked materials are formed by copolymerization, chemical modification, or radiation of linear polymers. The crosslinked network will swell but not dissolve, because the covalent crosslinks cannot be broken by any solvent and the swelling depends on the degree of crosslinking.

Superabsorbent hydrogels are used for the renewal of sandy soils and can reduce irrigation water consumption, improve fertilizer retention in soil, lower the plant death rate, and increase the plant growth rate [66, 67]. Most polymeric superabsorbents are based on sodium polyacrylate, but they are not suitable for saline water and soils [68]. Superabsorbent composites have been made by incorporating mineral into hydrogels to reduce production costs and improve salt resistance [69, 70]. Incorporating fertilizers into a superabsorbent network may thus be an effective way of increasing the utilization efficiency of both water and fertilizer [71, 72]. Superabsorbent composites containing **sodium humate** (Fig. 2.1) release the fertilizer over a long period, depending on the sodium humate content. Superabsorbent composites based on P(AAm-NaAA) crosslinked with MBAA has been shown to improve the water-retention capacity of the soil, regulate plant growth, accelerate root development, improve soil cluster structures, and enhance the absorption of nutrient elements [72].

1. Physical properties of hydrogels. The swelling capacity of hydrogels to retain water in their fully swollen state is an important characteristic. The equilibrium moisture-retention capacity of a hydrogel above about 55 % facilitates the diffusion of large ions into and out of its structure. The degree of hydrogel swelling, “hydrogel volume,” at the equilibrium represents a balance between the osmotic pressure force that drives water into the polymer (driving expansion) and the tension within the elastic contractability of the stretched polymer network that tends to expel the water from the swollen polymer (resisting expansion). The swelling pressure of the hydrogel at equilibrium is equal to zero. Hydrogels undergo reversible swelling and shrinkage which are a consequence of the affinity of their chemical structure, i.e., ionic form, to interact with water and also affects the moisture-retention capacities of hydrogels. The water-holding capacities of hydrogels allow spraying or blowing slurries of them with other agromaterials in soil reclamation [8, 60, 73, 74]. Hydrogels in the dry state are glassy with a

tendency to become soft, rubber-like after swelling in water or other polar solvents in which they are thermodynamically compatible. The ability of hydrogels to swell with water is governed by the free energy of their mixing and by the density of crosslinking [75]. Water penetration into the free spaces between the macromolecular chains of the hydrogel causes stresses which are then accommodated by an increase in the radius of gyration of the hydrated macromolecules. The entrance of the water into the free regions within the polymer favors the elongation and expansion of the polymer chains, and is increased by the strong hydrogen bonding interactions between the water and the polar functional groups on the polymer chains [60]. The water amount in the hydrogel can be regulated by suitable shrinkage or expansion, i.e., by the distance between crosslinks with the macromolecular segment chains. The swelling water within the hydrogels can affect their properties [76–81]. The equilibrium water content measured by gravimetry is the ratio of the weight of water in the hydrogel to the weight of the swollen hydrogel at equilibrium hydration [8, 13, 60, 73, 82, 83]. The equilibrium degree of swelling of a hydrogel is determined by the factors influencing coil density: hydrophilicity and concentration of ion-exchange groups on polymer chains, density and nature of the crosslinking, nature and degree of dilution solvent during polymerization, polymer chain mobility, branching, stereoregularity, as well as the type, concentration, and dissociation degree of solutes in solutions.

- 2. Mechanical properties of hydrogels.** Gel coils are not hard, but soft and easily deformable, due to the large freedom of segment movement, which are not able to move as units and thus not able to flow and the extent of the segment movement is dependent on coil density, solvent content, constitution of the chains, and the degree of crosslinking. With increasing crosslinking, the gels become hard and brittle because the chain segments between crosslinking points become short and the possibility for movement become small. The coils of gel are forced to a less probable state on deformation and with a decrease in the entropy of the system. Thus, the elastic retractive force of the gel (elasticity) is a characteristic property of the gel at low degree of crosslinking, in which the deforming force is not sufficient to bring a permanent deformation after removal of the deforming forces (stress), i.e., the gel returns completely to its original state before deformation of higher entropy. The gels have lower mechanical strength than solvent-free polymers, because the solvent isolates polymer chains from each other. In the swollen state, a hard, brittle gel becomes soft and rubber-like with low tensile strength and modulus. This solvent effect on mechanical strength has a profound effect on the lifetime of the gel in use. The elasticity and rigidity of hydrogels are governed by their chemical structures and affect their mechanical properties, such as the modulus of elasticity, degree of swelling, permeability and diffusion, and optical properties, which can be governed by the polymerization technique and conditions, the diluents, monomer structure, crosslinking density and hydrogen bonding structures, ionic and polar interchain forces, and the water-binding properties of the hydrogel [3–7, 84].

3. **Hydrogel application methods.** There are two methods for applying hydrogels as soil conditioners to stabilize the surface of soils to inhibit crust formation and improve water-holding capacity or to improve poor structure at greater depths by aggregation and to enhance plant growth. (1) *Dry method to subsoil.* Dry polymer such as PAAm or PVA is applied to the subsoil by mixing with the sandy soil into depths of about 15–25 cm and then subjecting to wetting for swelling prior to cultivation. After the polymer has swollen the soil structure is improved and the water penetration and retention capacity increases, decreasing water runoff and erosion. This method is applied for long-term intentions as the polymer has to absorb water prior to becoming beneficial, it is not recommended for immediate sowing. (2) *Wet method to topsoil.* The polymer solution is sprayed onto initially wetted topsoil, followed by drying to create water-stable aggregates that resist erosion [85–87]. This method is particularly well adapted to sowing immediately afterwards and can also be adopted to reduce water consumption in irrigation systems where water losses occur due to the soils' poor ability to retain moisture. These wet polymer methods can also decrease soil erosion by being applied to topsoil or to driveways of irrigation [88, 89]. Surfactants have positive effects on aggregate stability [90, 91], hydraulic conductivity [92, 93] and the distribution of conditioners [94].

2.1.1.2 Hydrogel Applications

The application of polymeric soil conditioners as additives to soils to improve their aggregate conditions can be extended into other areas: to reduce soil erosion and to prevent crust formation and general stabilization.

- (a) **Soil fixation** treatments of poorly structured soils are to improve stabilization and solidification of soils by varying the physical and chemical features of soils for construction and other structural applications where soil movement must be reduced or eliminated. The process generally requires the use of more than one additive. Polymers can be used to fix soil particles into aggregates by incorporating a crosslinking agent with them in the soil. They can be incorporated to improve water retention in the soil and provide a better growth medium. This technique is designed to allow crop cultivation without irrigation in areas where natural rainfall is inadequate due to drainage and evaporation losses or long dry seasons. Polymers can enable the existing water supply to be used more efficiently.
- (b) **Soil conditioning** aids for increasing the available water content of soils, for improving plant growth, and reducing irrigation requirements due to reduction of water loss and evaporation, thus, allowing the intervals between irrigations to be increased. The improved water retention in the soil will protect the plants against hydric stress. This is particularly suitable in arid areas where agriculture is marginal due to infrequent rainfall. Polymers can be incorporated in the soil to improve soil structure and water retention by reducing leaching and

increasing water supply to the roots. Hence they improve germination percentages and early growth, and reduce plant mortality during transplantation and simplification of transportation of plants. *Sandy soils* may allow good aeration but fail to retain sufficient water. They may not be able to meet the water demands of a plant, resulting in plant dehydration and wilting stress. Repeating this hydric stress during the growth period can seriously inhibit plant growth. In these soils, the polymers can agglomerate the sandy particles and hence increase the water retention capacity. *Clay soils* inhibit plant development by inadequate oxygen levels, excess of carbon dioxide, and lack of drainage. These soils have the tendency of forming compacted crusts that inhibit seedling germination and emergence and restrict early root growth, which may be compensated by overseeding and excessive irrigation during germination. Polymers can also be employed to improve the structure characteristics of clay soils, where the swelling of the polymer particles breaks apart the structure of the soil and leads to an improvement in aeration, better drainage, and provide a stable aggregate in the soil thus reducing the crusting effect. This dual action of improving water infiltration and reducing erosion enhances seedling emergence and accelerate early growth.

Hydrogels are of great interest in soil reclamation as (1) soil amendments to modify the water status of growth media, (2) seed amendments, and (3) transplant aids [8, 60, 75–77, 95–118]. Hydrogels used as soil conditioners for improving soil properties [8, 119–121] include: plastic foams [122, 123], PS [124], H-SPAN copolymers, crosslinked P(KAA-AAm) gel [125], P(KPA-PAm) [126], and PAAm gel [21]. Hydrophobic conditioners, such as bitumen [122], are also employed in emulsions for reducing soil runoff and saving water in subsoils, especially for in tropical rainy zones [8, 128]. They decrease crust firmness of sandy and a clay loams, decrease infiltration rates, and increase water retention. Incorporating hydrogel polymers as polymeric plant growth media by spraying onto soil surfaces as a thin soil layers results in: improved plant growth and size [66], improved crop yields, superior water relations of plants growing in soils [129, 130], improved moisture retention in the root zones during plantation, more healthy transplants, i.e., reduced growth retardation after transplanting, increased water-holding capacity, reduced soil compaction [131], and improved nutrient retention, efficiency, and uptake. Nutrient-amended polymers serve as effective seedling growth media for short-term seedling production [129, 132], reduce nutrient leaching losses [133], improve soil fertility and prevent soil erosion [95, 129], increase time of leaf wilting that improve root development and increase yield [134], decrease irrigation frequency [73, 74, 135], and provide adequate aeration to seedling roots by pore creation between gel granules upon hydration. The combination of hydrogels and wetting agents produces more effective water-holding capacities, which are influenced by the type of irrigation method (overhead sprinkler, trickle emitter, flood and drain trays, capillary mat, etc.) [136].

Naturally aggregating polymeric agents in soils such as polysaccharides and protein are formed as a result of chemical and fungal reactivities [137–140] or

due to the interaction between clays and organic matter in soils [141], e.g., cationic starch-grafted copolymers possessing diethylaminoethyl- and 2-hydroxypropyl trimethylammonium ether groups have been shown to be effective stabilizers of surface soils [142]. In addition to the use of H-SPAN-containing carbamoyl and carboxylate groups in seed and root coatings and thickening agents, the former have the potential of increasing the water-holding capacity of soils, especially of sandy soils [13]; it is insoluble in water and, when wet, produces gel sheets of large surface area [143] and has been used as a soil conditioner in agriculture to increase the soil water-holding capacity of sand and delays moisture stress because it can absorb high amounts water [60, 144–147]. The addition of this material to soils has a reducing effect on the water-retention properties and the infiltration rates of soils [148].

PAAm gels are useful in stabilizing unstructured sandy soils and in forming water-stable aggregates in soils, preventing surface crusting [61, 149, 150] and reducing soil splash and runoff [151, 152] besides settling and consolidating soils and dust against wind [153, 154]. They are effective in improving the physicochemical properties of sandy soils that have favorable effects on water infiltration and decrease the erodibility of soil, thus reducing the requirement for irrigation and increasing crop yields [155]. Structural improvements due its hydrophilicity results in a better infiltration and drainage by increasing the holdup of water and reducing water evaporation from the soil. PAAm has successfully been used in treating water repellency [156] in alluvial soils and has improved seed germination, plant growth, and crop yields [62]. The erodibility of silt loams and dune sand are reduced by PAAm addition. However, it increases soil aggregation, porosity, aeration, and imparts friability, which lead to an increase in the infiltration rate and storage of water in the subsoil. Besides soil reclamation by use of PAAm as soil conditioner, it imparts improved chemical and bacteriological fertility that increases the yield of crops. These have been attributed to the continuous supply of nitrogen, increasing nitrification or nitrate content in the soil, and enhancing soil bacterial growth and microbial populations, and imparting friability which results in increasing rooting. PVA has also a stabilizing effect on soil surfaces and its distribution is determined by: method of application, application rate, and the polymer's molecular weight [88]. PVA is more effective in stabilizing the soil surface at very low application rates than root exudates and soil organic matter, due to its strong adsorption. Soil conditioners used for soil reclamation and aggregating and stabilizing soils have been comprehensively reviewed previously [157–165].

- (c) **Soil erosion control.** Soil erosion and runoff are serious land degradation problems in arid and semiarid regions caused either by rain or wind. It is a significant environmental problem for agricultural lands that results in destruction and eventual abandonment of the land and the loss of civilization itself. Sediment in runoff from agricultural landfills in reservoirs and rivers endangers aquatic life and reduces soil productivity. Chemicals transported with the sediment may cause water quality problems in lakes and streams. Land classification

is based on the capability of crop production, as determined by the degree of limitations and hazards, and involves the following parameters: soil type, erosion degree, drainage extent, presence of rocks and stones as impediments to cultivation, water-holding capacity, and the amount and distribution of rainfall. These soils are characterized by relatively high levels of salinity and low structural stability, and irrigational erosion reduces the productivity of irrigated soils, the yield of grain, forage, and industrial crops, and lowers the quality of the produce. Soil erosion by water can be reduced or controlled by varying the irrigation technology and its mechanism. This can include the ability of a water flow to detach and move particles along the surfaces and the resistance of the soil to the force of irrigation water, and by providing adequate supplies of the irrigation water for agricultural and crops uses and removing excess water from the soil surface. Long-term control of soil erosion is usually achieved by growing plants. However, until the plants are fully established soil erosion will continue, thus reducing the efficiency of the early cover. Polymers can be applied to aggregate the soil by surface treatment and hence to provide surface stabilization during the early phase of crop growth. Thus, hydrogels act to reduce erosion from water and wind by stabilizing the surface layers, reducing runoff and soil losses, decreasing the infiltration rates of water into the soil, and increasing the hydrophilic nature of the soil surface which aids seed germination and emergence. The combined effects of reducing runoff and promoting a higher level of moisture to be retained in the soil reduce erosion and improve plant growth. In addition to their use as straw mulch, hydro-seed hydrogels are used to reduce erosion by increasing soil strength by aggregating the soil particles, absorbing the impact of raindrop energy, and promoting plant growth by protecting seeds and seedlings, maintaining aggregate stability, and increasing soil moisture [37, 166, 167].

- (d) **Seepage control** can be achieved by certain polymeric hydrogels which form water-impermeable layers or membranes in the soil and can be efficiently used to control the movement of water and dissolve salts through their interactions with charged sites on the surface of the soil particles. Thus, hydrogels are used for seepage control by the formation of membranes in the soil that restrict the movement of water thereby protecting crops from salt damage. This technique can be used to save irrigation water, to control salt damage to crops caused by irrigation in arid soils and finally to prevent the seepage of such water into rivers and reservoirs.

2.1.2 Container and Pot Plantations

Cultivation in containers (flower pots) is characterized by features that differ from those in open field cultivation. The volume of soil available to the plant is smaller and less deep than in an open field. This results in a reduced reservoir of water and nutrients available to the plant. To compensate this deficiency, regular watering and

fertilizing is required in order to obtain acceptable growth rates. In the open field, plant roots can grow freely towards water sources, which is not possible in the containers. The roots in a container tend to grow in circles which is detrimental to the overall aeration and drainage. In all types of soil the amount of water decreases with compaction, this means that the deeper compacted layers contain less available water than the surface porous ones. Soil conditioner is added to prepare the container soil for improving its physical properties by reducing its density, increasing its porosity, and thereby increasing the amount of air and water. Most bedding plants are grown in small containers that make them highly susceptible to water stress. Avoidance of water stress and protection against possible plant injury would be of significant value to growers and retailers.

Containers and pots for plants made from molded PS or PP have almost completely replaced the traditional clay pots both for commercial undertakings and for the private gardener. Plastic pots have the advantage of being easy to clean, of lighter weight, and losing less water by evaporation through the sides. Black PE film containers are cheaper and consequently have become accepted as the norm by the majority of nurserymen. Small containers and cylindrical pots of varying sizes formed in PS are widely used commercially for exporting and transporting young plants. With more people living in multistorey apartments there is an increasing demand for plant troughs which are designed from molded PP so that there is a constant supply of moisture available to the plant roots. PE film bags are used for the cultivation of mushrooms in underground quarries [168]. Various efforts to reduce water loss and increase market life of larger container-grown plants involve the use of hydrogels that act as rechargeable reservoirs holding many times their dry weight in water. Several beneficial results of hydrogels include greater nutrient availability, improved aeration and drainage, increased market life of container-grown plants [135], reduced watering requirements, improved top growth and flowering, better root development, and increased yields [169]. Hydrogel incorporated in the growing media of bedding plants grown in different size containers generally increased time to wilting as demonstrated by the reduction in internal water tension under stress due to hydrogel incorporation in the growing medium. High rates of hydrogel incorporation were as effective in increasing time to wilting in small containers as was doubling container size [73]. Various forms of soil amendments and antitranspirants have been used for many diverse crops [135]. In floriculture with hydrogels, their effects on water-holding capacity of media in pot-grown crops [73] improve aeration and drainage of the medium [169], improve market life of container grown plants [170], and reduce watering requirements. A delay in wilting and moisture stress can be decreased by incorporation of a hydrogel into the medium [73]. Film-forming antitranspirants and hydrogels affect net photosynthesis and water loss during water stress [88]. When plants are transplanted into medium with a hydrogel, such as PEO, water loss is lowest for plants where both the foliage and medium are treated. As water stress developed, net photosynthesis decreased, reaching a zero rate at wilting. Crosslinked PAAm, P(KPA-PAm), polyamide and cellulose-ether containing FeSO_4 are used for greenhouse pot plants, to improve the storage of available soil water and are effective in supplying Fe to plants [26, 171].

Water retention in potting soil is an important factor in irrigation management of potted plants and may be influenced by amendments soil conditioner: hydrogels or wetting agents [172–176].

2.1.3 Gel Planting and Transplanting

Hydrogel applications in agriculture include their addition to soils as gel planting [3–7], incorporation into hydro-seeding or hydro-mulching systems where they serve as tackifiers for seeds and as germination aids, and are added to water as a gelling agent for fluid drilling of pregerminated seeds [60, 75]. There are two types of *transplanting* to beds: (a) trees and shrubs are normally transplanted with a dry root structure. This results in a requirement for constant watering while the root system becomes reestablished. This water problem is obviously more severe in dry regions with sandy soils. (b) annuals are transplanted as cuttings and seedlings. During plant transportation over long distances there is a problem of provisioning adequate water supplies to the plants. Polymers can be used to provide water without any spillage.

2.1.4 Seed Coating Germination

Planting seeds is one of the most important steps in the process of propagating plants [177]. The most critical phases in the growth and development of plants are those of germination and establishment. The successful establishment of agricultural crops from seed is often restricted by poor soil moisture levels, especially in arid or semiarid regions. Improvements in soil-water relations should enable more even and predictable germination and establishment. Water uptake by seeds and subsequent germination rates are strongly influenced by moisture potential at the seed-soil interface [178, 179]. Polymers with binding tensions for water in the plant-available range have the potential to increase moisture levels around germinating seeds. Amendment of plant growing media with hydrogels often increases water-holding capacity and improves plant growth [180, 181]. Thus, plants grown in hydrogel-amended media require irrigation less frequently than plants in nonamended media, due to the effect of hydrogels on the surface properties of soil particles [148]. The influence of hydrogel-amended soil on the growth of transplants of some vegetables shows increased yields over other growing media [182]. Application of the gel slurry to the root zone of plants before transplanting prevents roots from drying, reduces wilting and transplant shock, and improves plant survival especially under poor field conditions. However, the more important application of hydrogels is in coatings for seeds to absorb water and is coated directly onto the seed surface. After planting, the hydrogel absorbs water thereby increasing the rate of germination as well as the percentage of seeds that germinate. The type of hydrogel seed

coatings can be adapted depending on the application, to delay germination, inhibit rot, control pests, fertilize, or to bind the seed to the soil [183–188]. Seeds have also been coated to increase the size of small seeds to permit machine planting [3–7] to greatly reduce the waste of seed, and the cost of thinning the excess plants is eliminated. In such cases, the primary objective is to increase the bulk of the seeds and to include pH buffers, fungicides, trace nutrients, or other beneficial constituents to enable better plant establishment and growth [118] and to supply plant-available water [114] and reduce evaporation rates [108].

Seed coating can improve germination, reduce the germination time, improve root development in the early stages of growth and accelerate the harvest. By coating seeds with hydrogel by homogeneous mixing, moisture supplies can be improved in soils. This application method is commonly used with starch copolymers because the coated seeds have small particle sizes when dry and form a gel mass upon hydration. The gel adheres easily to the seed and the coating allows high water potentials to be maintained both inside the seed and within the protective layer [183–186]. This also enhances imbibitions of water prior to germination [9]. Powder polymer can adhere to the surface of the seeds by electrostatic attraction. When the polymer becomes wet it will lose its ability to stick to the seed and cause considerable difficulties of handling, hence the coated seeds are kept in an airtight container. In agricultural plantations and plant growth development, polymeric wetting agents have been used either as soil amendments for gel planting of germinated seeds [189, 190], for coating the root zone of seedlings before transplanting [3, 34], or as seed coatings for germination [185, 191]. However, there are some problems associated with seed coatings: (1) the coatings often do not stick to the seed well and can chip and crack, (2) thick coatings impede the rate of the flow of seeds in planters.

Hydrogels such as PAA and PVA are more commonly applied by mixing them dry into the growing medium and then irrigating to allow full hydration and the formation of a gel. In such cases seed and gel are not in direct contact as they are with the coating method [187, 188]. Polymeric wetting agents used in seed coatings include: PVA, H-PVAc, PVME, P(VME-MA), poly(vinyl pyrrolidone), agar, H-SPAN, starch copolymers, PAAm copolymers and water-soluble cellulose ethers, such as carboxymethyl- and hydroxymethylcellulose. However, clay seed coatings decrease germination because coatings reduce oxygen movement into the seed [9, 191]. In addition to the use of H-SPAN for increasing the water-holding capacity of sandy soils, its potassium salt results in viscous solutions which have a wide variety of applications like seed and root coatings and thickening agents. The gel absorbs water and holds it at the seed surface, thus increasing both the germination rate and the percentage of the total number of germinated seeds. H-SPAN coatings have been used as seed coating to enhance stand establishment and plant growth of sweet corn [184], soybeans, cotton, corn, sorghum, sugar beets, and leafy vegetables [85]. Elastic PU foam containing soil has been used as an effective plant growth medium supporting the root structure of a plant placed in the substrate foam [178, 179]. An example of a plant growth medium suitable for use as a matrix material to support the root structure of a living plant is foamed synthetic polymeric material impregnated with finely divided mineral particles and microorganisms suitable for

rendering the minerals available for plant use and which may additionally contain a seaweed concentrate for supplying additional vitamins and minerals to the plant [192]. Additionally, plant growth media can be improved by using hydrogels for seed coatings that may incorporate other additives such as insecticides, nematocides, fungicides, repellents, herbicides, growth regulators, nutrients (N, K, P fertilizers), and bacteria capable of exerting a favorable effect on the germination and growth of plants.

2.1.5 Soil Aeration

A good soil for growing plants should have air gaps for proper gas circulation and exchange. Earthworms are significantly involved in aerating the soil through digging through the soil allowing gases to pass. Loosening of heavy soil can be effected by the addition of foamed plastics in granular or chip form. Expanded PS as a waste product is now being used as a soil additive to improve soil structure and stimulating root formation, applied for plant propagation and potted plants. It is also used for drainage in place of conventional drains. Urea-formaldehyde foam is also used for this purpose having the advantage of moisture retention, unlike PS, and decomposing only slowly in the soil and supplying nitrogen to the plants [193].

2.1.6 Soil Sterilization

Soil sterilization has many benefits which provide secure and quick relief of soils from organisms harmful to plants such as: metabolites, bacteria, viruses, fungi, nematodes, and other pests, and killing of all weeds and weed seeds. *Soil heat sterilization* is often performed by heating the soil when covered with PE sheets by solar radiation during summer or during periods of intense sunshine and clear skies [191]. The process raises the soil heat and temperature, killing soil-borne pathogens and pests that would lower the yield of field crops. This nonchemical management of soil pathogens is an eco-friendly and inexpensive technique to control pests and diseases in the soil for a profitable yield. *Soil steam sterilization* (fumigation) is a farming technique that sterilizes soil and plants with steam or agrochemicals in open fields or greenhouses [194]. It consists of injecting into the soil, to a depth of several centimeters, steam or volatile chemical products while the area is covered with a sheet buried at the edges. Fumigation involves injecting into a well-prepared plot, covered with PE film stuck down at the edges, a toxic liquid which evaporates only slowly so that the vapor is maintained in contact with the soil for sufficient time to destroy all the unwanted plants and animal parasites. For preparation, all roots should be eliminated and the soil watered for several months in advance, in order to speed up the decay processes. Fumigation allows crops of high profitability

to be grown without interruption on the same ground from year to year [192]. Fumigation cleanses the ground getting rid of weeds and pests such as nematodes, insect larvae, and microorganisms responsible for plant diseases. Harmful pests and weeds are also killed by induced hot steam. Steaming is the most effective way for a quicker growth and strengthened resistance against plant diseases and pests. Different types of steam application are available including substrate steaming and surface steaming. Several methods are used for surface steaming such as area sheet steaming, hood steaming, sandwich steaming (combined surface and depth injection of steam), plow steaming, and vacuum steaming with drainage or mobile pipe systems. Particular factors are considered in choosing the most suitable steaming method such as soil structure, plant culture, and area performance.

2.2 Polymers in Plant and Crop Protection

Polymeric materials have extensively been involved in the mechanization of farming and for the protection of plants and crops [195–215]. Covers are placed over growing plants for protecting them against adverse weather conditions and for stimulating an artificial microclimate for precisely controlled cultivation. Greenhouses, tunnels, direct covers, windbreaks, mulching films, and protective nets against birds are all examples of such action taken for plant protection. Such measures are also taken for shading not only to provide protection against weather damage but also to control photosynthesis. Polymeric windbreaks and protective nets play important roles in as antifrost measures. The use of films, set around the plants is more effective to create a channel for plant protection against damage by cold weather, excessive insolation, and animals. The purpose of protection is to increase the crop and accelerate maturation, or to extend the cropping season. The main form of protection is achieved through regulating the temperature and moisture levels, and eliminating wind and possible damage from the adverse weather conditions as high temperature, hail, or wind. Such protection can also modify the spectrum of light reaching the plants which modifies their growth. The mechanics of this type of protection primarily involves a covering of film, but netting is used when shading is required to reduce temperature. Windbreaks are a permeable barrier rather than a covering. Additional advantages of greenhouses and tunnels are that they provide shelter for the workforce. The other form of protection is to prevent pests from reaching the plants, which is generally achieved with netting or mesh. While a film covering could protect against birds, preventing other pests is usually more cumbersome as the artificial environment suits the pest as much as it does the crop. The most widely used protection is for vegetables but is also used for fruit, flowers, and nursery stock. Covering protection can be effectively applied in a relatively cold climate where cropping may not even be possible without protection, and can also be applied in a relatively warm climate where improving is more effective and important especially in economic terms.

2.2.1 Creation of Climate

The fate of plants is determined by microclimates occurring within an area to a limited extent. Such environments can be artificially created by means of various types of plastic coverings, such as mulch and greenhouses, in which temperature, humidity, and radiation are controlled. The air temperature inside and outside a covered structure varies during the course of a day and the external temperature depends on the region and the time of the year. Films are used to create microclimates in the form of mulching, low tunnels, various shelters, and greenhouses. They are also used in soil sterilization by fumigation, and also in the handling of fertilizers and their distribution in the soil in association with water. In general, under *transparent film*, the temperature of the soil rises during the day according to the season and type of soil and also according to the level of sunshine and the water content, while under *black film*, the soil temperature is only slightly higher than the control. Under *white film*, the soil temperature is always lower than for uncovered soil; these are used either in regions with a high levels of sunshine, where it is necessary to reduce the transmitted radiation and soil temperature, or in regions of low luminosity, where there is a need to increase the amount of reflected light on the lower and middle leaves. Thermal insulation is characterized by the specific heat and the thermal conductivity in relation to the specific gravity and the thermal diffusivity.

2.2.1.1 Mulching

Mulching is a protective covering on the soil around plants for plant protection with the aim of helping growth and crop earliness, productivity, and partial protection of the produce by suppression of weeds [214, 216–218]. Mulching plays a major role in plant cultivation by creating at the soil surface some protection and microclimate which is favorable in respect to temperature distribution and retention of humidity, surface fermentation, and the supply of carbon dioxide to the plants. Prolonged dry periods have an adverse effect on the growth and development of crops particularly in light textured soils. Therefore, it is essential to minimize the losses due to evapotranspiration in order to ensure adequate water supply to the crop during dry periods. Mulching is particularly important where water needs to be conserved, when it is necessary to heat the soil lightly in order to obtain growth, and also when there are many weeds. Mulches are used for plant protection with the advantage of easy application over hydrogels that are used as binding agents for soils [219–221]. The main objectives and benefits of mulching protection for plant growth and yield include: elimination or reduction of weed growth problems through radiation control, control of insect infestation, better retention of moisture in the soil [195], avoidance of soil compaction [222], avoidance of leaching [223], improvement of microclimate temperatures and humidity [224], increased plant growth by carbon dioxide retention under the film, soil protection from erosion and leaching of

nutrients, action as thermal insulation for the roots in cold climates (in winter), protection from frost and the action of torrential rain, saving and retention of irrigation water, saving in labor, increase in root growth; earlier fruiting; reduction in the unfavorable effect of possible soil salinity [203], reduction of evaporation by insulating soil surface against direct solar radiation and by obstructing vapor diffusion, suppression of transpiration losses without reduction in photosynthesis. Effective fumigant mulches require reduced-porosity films which reduce the escape of volatile chemicals, i.e., nematocides, insecticides, herbicides, etc., and therefore allow for lower application rates. The use of polymers for hydro-mulching is particularly beneficial in areas with water deficiency and in sandy soils with rapid drainage. The plastics used for mulching soil surfaces are of various types.

Mulch film types. The advantages of plastic film mulching over traditional mulching are in its light weight, that it covers a much greater area per volume than natural mulches, its being amenable to mechanized installation, and its lower cost. The most widely used plastic film is PE. Several specialized types of PE film include heat-resistant film, heat-retaining film, water-absorbing antistatic film, and photodegradable film. A heat-resistant PE film for warming the soil will enhance absorption in the long wave region of radiation that enables the temperature under the film to be higher than when under normal PE film. In order to facilitate the passage of the plants through the film, it can be perforated at the time of sowing, but slit film is used extensively. Moisture-absorbing antistatic PE film with enhanced permeability to UV radiation is used primarily for seed beds, as it does not become dusty and therefore creates better conditions for growing plants inside hothouses. The film's surface characteristics also prevent the deposition of condensed droplets, increasing the yield of vegetable crops as compared to normal PE film. PE-film tunnels and perforated flat PE film allow better use of natural resources such as solar energy, water, and soil. Shrinkable PE films are used for sheet steaming in horticulture. The quality of the used film for mulching with satisfactory term service can be distinguished by the film color. Mulch films are classified into the following types:

- (a) **Transparent film mulching** enables rapid heating of the soil as well as conserving moisture and protecting the soil. The use of transparent film increases the soil temperature during the day according to the season, type of soil, the level of sunshine, and the water content, thereby increasing the activity of the volatile fumigants within the enclosed area. Clear PE film which is an effective heat trap is commonly used as mulch and soil fumigation in the production of food crops. However, weeds will grow under clear film and soil temperatures may increase under the film. The film transmits most of the incoming radiation which warms the soil and the moisture droplets that collected on the underside of the film block; much of the radiation is emitted as the soil cools at night. Most of the heat loss from the soil is trapped under the clear film and a greenhouse effect that stimulates and forces plant growth is maintained under the cover. Mulching with LDPE has been described for various plants [198, 200, 204, 213]. Transparent PE is more effective in trapping heat than black or smoke-gray films. Soil temperatures may rise under clear films, as compared to black films.

Heat loss at night, as the soil cools, is lessened by polymer films. Weed control has been reported because of solar heating of the PE mulches.

The use of transparent films does not prevent weed growth and their short life requires the use of high quality PE film containing UV stabilizer for long durability. Special photoprotective systems as UV-light absorbers, quenchers, radical scavengers, and hydrogen peroxide decomposing agents are added to the films to delay the effects of these environmental factors. UV-light absorbers as benzophenone and benzotriazole are frequently used in polymeric films. While the addition of UV absorbents increases the service life of the film, they have the disadvantage that their effectiveness is dependent on the thickness of the film to be protected. Quenchers are photoprotective compounds that can take up and dissipate energy that has been absorbed by chromophores, such as hydrogen peroxide, which are present in PE film. Organic nickel compounds are quenchers that also act as decomposing agents of hydrogen peroxide. Hindered amine light stabilizers as photoreactive compounds are referred to as scavengers, they absorb light and do not act as UV absorbers or quenchers.

- (b) **Black and colored film mulching** is opaque to incoming radiation and hence it is effective in preventing weed growth. The increase in crop yield by using black PE mulch is based on the elimination of weeds and the avoidance of soil compaction. Thus, the use of black plastic mulch eliminates the need for mechanical cultivation often associated with root damage and stunting or killing of plants. The film used in mulching should retain in position for several years. Opaque films reduce maintenance work. Films and sheets used in mulches are generally opaque LDPE, PVC, PB, and PEVAc. PE films for agricultural applications need to have high strength and elasticity, resistance to wind forces, and a long service life. Since PE mulch cannot be reused and does not degrade between growing seasons, it must be removed from the field and disposed of, or mostly produced from combination of PE with PEVAc. In addition to black and transparent PE films [225], black paper coated with PE [226], aluminized PE, and other opaque films made of EVA and PVC are used. Black films are used extensively for strawberry cultivation, for humidity control, and suppression of weed growth [195, 209].

Colored mulching is effective for a range of vegetables (cucumbers, melons, peppers, corn, cabbages) but a single color mulching is not suited to all crops nor effective against all pests. Red mulch gave best results for tomatoes for growth whilst silver mulch controlled whitefly. Similarly, colored mulch has reduced thrips on leeks. UV light reflected by silver mulch repels insects whilst a plant may be stimulated by the colored light reflected giving the impression of there being competitive plants nearby. Reflective films, whether opaque, white, or metallized, can be used in low light conditions to concentrate sunlight onto the plants to increase photosynthesis. Blue mulch produced best results for peppers [227] due to the reflection of photosynthetically active wavelengths and raised soil temperature, whilst black mulch on inclined beds gave improvement of pineapple yield and sugar content [228]. Yellow-brown films delayed the incidence of tomato yellow leaf curl [229]. The use of black mulch in temperate

climates has some advantages for asparagus cultivation [230]. Colored mulch made of rubber from recycled tires avoids the need for otherwise frequent replacement [231, 232].

- (c) **White film mulching** lowers soil temperature in relation to uncovered soil. This type is used either in regions with high levels of sunshine, where it is required to reduce the transmitted radiation and soil temperature, or in regions of low luminosity, where there is a need to increase the amount of reflected light on the lower and middle leaves.
- (d) **Photo-/biodegradable film mulching** is significantly used in agricultural mulch as it is completely degraded in a short time when buried in the soil at the end of the crop season. Conventional films can cause problems during harvesting or during cultivating operations and their removal and disposal are costly and inconvenient. Therefore, there is a growing interest in the development of biodegradable or photodegradable films with short service lifetimes. A large number of polymer types have been designed for controlled biodegradation by soil microorganisms and that contain light-sensitizing additives for photodegradation. Coated starch-based films withstand weathering conditions commonly associated with crop production; after a period of time, depending on the amount of coating, they will become brittle and rapidly deteriorate. The amount of coating needed depends upon the crop application. Starch-PVA film is coated to yield a degradable blend film that resists weathering conditions associated with its use as agricultural mulch for controlled periods and then rapidly deteriorates into small particles which mix with the soil; the time at which decomposition occurs depends upon the thickness and amount of coating [233]. Another approach for the preparation of biodegradable film is by inserting biologically labile compounds as starch into normally stable PE chains. The labile starch component is then rapidly consumed by soil microorganisms, leaving the resistant PE in a porous state that is more easily accessible. However, the compatibility between starch and PE is poor due to their difference in hydrophilicity, but starch can be compounded successfully with various proportions of LDPE and PE containing carboxylic groups as PEAA to form starch-PE films. PEAA acted as a compatibilizer between starch and PE. By soaking starch-PEAA mulch films in urea solution, the leached urea would enter the soil and be available as a nitrogen fertilizer. Replacing a part in these formulations with PVA increases tensile strength values while it reduces percent elongation. Three polymeric gels based on starch-PEAA-LDPE [127, 234], starch-PVA [235, 236], and starch-PVC [237] have designed as biodegradable films that possess clarity, elasticity, and water resistance for the use as agricultural mulch [234]. Polylactone and PVA films are readily degraded by soil microorganisms; the addition of iron or calcium accelerated the breakdown of PE. Degradable mulches should break down into small brittle pieces which pass through harvesting machinery without difficulty and do not interfere with subsequent planting.

Photodegradable PE film is used for mulching the soil in vegetable growing. The film breaks down as a result of solar radiation and the degradation products combine with the soil [238]. A particularly interesting photodegradable system consists of a mixture of ferric and nickel dibutyldithiocarbamates, the ratio of which is adjusted to provide protection for specific growing periods. The degradation is tuned so that when the growing season is over the plastic will begin to photodegrade. Another additive system for this application includes a combination of substituted benzophenones and titanium or zirconium chelates. The principal commercial degradable mulch is photodegradable poly-1-butene. PE films suffer from decomposition by environmental influences such as light and atmospheric oxygen, hence the problems encountered with the collection and disposal of the used films have been overcome by the use of photodegradable film [213].

2.2.1.2 Growing Enclosures

Polymeric materials are extensively used in constructing materials for growing enclosures as for: (a) *Greenhouses* – for crops and flowers out of season, starting plants for early transplanting, and controlling the environment for forcing and early maturing of plants. (b) *Row covers* – are small, temporary, field greenhouses, used to protect field plants against damage and to force earlier maturing. (c) *Hotbeds and cold frames* – accelerate the growth of plants to be used for transplanting. Economy of construction was a major factor leading to the use of plastic films as greenhouse glazing.

Among the polymeric materials used as growing enclosures are the cellulose, rigid and flexible PVC, PE, PET, PMMA, glass-reinforced polyesters, PSAN, and PS. Clear films or sheets transmit solar radiation. PVC, polyesters, and PE effectively block the passage of radiation absorbed by soil, plants, and frames inside the greenhouse during the day to the outside air as the soil and greenhouse contents cool. This provides a small heat reservoir during the cool night hours, i.e., it reradiates radiation as heat energy at night, and therefore reduces heating costs. Condensed moisture on the inside of the film assists in trapping the radiation.

- (A) **Greenhouses** are large structures in which it is possible to stand and work. Traditional greenhouses were wooden or metal framed with glass panes. Use of clear, flexible, light-weight plastic covers has made possible the design of new types of greenhouses. The idea of growing food at controlled temperatures all year round and the ability to extend the growing season has led to the wide use of greenhouses in agriculture to create protection to the plants grown. The greenhouse is a structure with a covering and walls, either flat or curved, transparent or translucent, in which it is possible to maintain an atmosphere more or less conditioned as regards temperature, humidity, and radiation energy, so as to encourage crop earliness, improve the yield, safeguard the crop, and make more effective use of water. The control and possibly the variation of the

artificial climate thus created are suitable and seasonable as a result of using satisfactory automation and that the manual or mechanical operations are made easier by the topography and the arrangement of the sites. Greenhouses attract heat because the electromagnetic radiation of the sun warms the plants, soil, and other components within a greenhouse. Air is warmed from the hot interior area inside the structure through the roof and wall. Thus, the main objectives of greenhouses are the ability to extend the growing season and sowing, control of growing conditions (temperature, light, and moisture) for plants inside the greenhouse to produce the desired new kinds of plants, protection from birds and animals, facility in controlling pests and diseases, less physically demanding than fields and open crop spaces, and the possibility of reducing gardening costs. The main advantages in using plastic greenhouse covers include lower maintenance costs, less shadowing of the plants by rafters, maintenance of higher humidity which results in faster growth of plants, and ease of replacement, better control of the internal atmosphere, and lower heating costs. However, the disadvantages in the use of plastic greenhouse covers are associated with heating, heat distribution, disease control in a highly humid atmosphere, moisture condensation on the underside of the plastic film, and the tendency of films to crack during extremely cold weather.

The parts of a greenhouse include: framework (wood or aluminum frames), glazing (safety glass, plastic wall or roof), foundation (concrete foundation, wall, slab/tile), and accessories (benches, shading, heating, air circulation, misting system). A detailed design and construction of plastic-film greenhouses involves consideration of the specific imposed forces generated by outside weather conditions of storm, rain, hail, and snow as well as crop and structural loads [239]. The standards for designing plastic-film-covered greenhouses provide rules for structural design, including requirements for mechanical resistance and stability, serviceability and durability, and the scope extends to cover the foundations.

Properties of Plastics for Greenhouses. Inherent limitations of greenhouse films are their modest strength and working lifetimes, although considerable improvements have been made by choosing adequate combinations of film and frame construction needed to ensure satisfactory performance in a given situation. The desired properties of covering films include the following: (i) *Density*: the framework can be lighter for plastic greenhouses than for glasshouses and the shading zones will be less in plastic greenhouses than in glasshouses. The light weight of plastic greenhouse construction and the resistance to impact make them easy to move for crop rotation while the rounded form helps to make them air-tight. (ii) *Transparency*: the permeability to solar radiation leads to effective heating during the day and is followed by rapid cooling at night, although this effect is compensated by the presence of condensed water on the internal wall or by the use of a double wall of film. The light transmittance of the covering films is high when they are new but there is considerable loss of light transmittance with ageing and if cleaning is not undertaken. (iii) *Heating*: this is more expensive for a glasshouse than for a double-walled plastic

greenhouse. (iv) *Air humidity*: plastic greenhouses permanently maintain a higher degree of humidity resulting from evapotranspiration due to their low permeability to water vapor [197]. (v) *Ventilation*: it is necessary to ventilate the greenhouses by low-speed fans early in the morning before the temperature rises. (vi) *Airtightness*: plastic greenhouses, particularly those with flexible film coverings have the advantage of superior airtightness as compared with glasshouses. (vii) *Resistance to hail*: plastic greenhouses are resistant to hail hazards.

Plastic films for greenhouse coverings act as filters, selectively allowing radiation of different wavelengths to pass. Visible light covers the photosynthetically active range of the spectrum which is essential for plant growth. When other requirements of water, temperature, carbon dioxide, and nutrients are satisfied, growth will depend on the amount of light received. In sunny conditions the covering needs to diffuse the light; this reduces shadows and the light is more efficiently used, plus that scorching is prevented. At night, the longer-wavelength IR emitted by plants and soil causes the cooling of the greenhouse. The lower the transmission of radiation through the covering the better is the heat retention, and the greater the “greenhouse effect” [240–242]. Adding fluorescent or phosphorescent molecules to a covering film allows certain wavelengths to be absorbed and re-emitted at more photosynthetically efficient wavelengths and the film becomes photoselective [243]. Both photochromic and thermochromic additives in greenhouse films accelerate growth and increase yield also effecting photodegradation [244, 245]. Water condensing in droplet form on the inside of the greenhouse covering reduces light transmission; drops falling onto the plants can encourage diseases and the drops act as lenses and may cause scorching. Films having antidripping properties have lowered surface tension so that water tends to form a film layer rather than drops and such materials are clearly advantageous. However, a disadvantage of antidripping films can be the attraction of dust in dry weather, but this can be alleviated in multilayer films by having antidripping characteristics on the inside [246].

Greenhouse Types. There are many different types of plastic greenhouses, each type having its own advantages and disadvantages. The classification of greenhouses depends on many factors such as cost, space area, the plant and crop type, the climatic conditions, terms of temperature control (hot, warm, cool), and the structural design [201, 202]. Greenhouses can be classified according to the materials from which their framework structures are made into the following types [209]:

1. **Flexible plastic greenhouse:** Most consideration of greenhouses is directed towards conditions in the temperate climates, but simple, cheap wooden frames with film or net coverings have been developed for warmer climates [239]. They are popular due to their low cost and can absorb sufficient heat. PE films have good mechanical properties and are used almost similarly as the covering material for flexible plastic greenhouse structures because of its lightweight and inexpensive cost; however, it deteriorates during summer

when exposed to the sun. Its breakdown due to UV rays can be avoided by using UV stabilizer. Soft, flexible, transparent PVC films are relatively stable but they attract dust and dirt from the air, and hence they must be washed from time to time. Reinforcing the PVC films with nylon or polyester fibers tends to overcome the deterioration of its mechanical properties. The use of thin, rigid PVC in greenhouses provides a significantly longer service life than flexible PVC or PE. However, improvements in the light stability and fungus resistance of flexible PVC have extended its service life beyond that of stabilized PE film for greenhouse covers. PEVA films are widely used as double-walled structures, while PP films are rejected because of the high rate of dirt pickup which considerably reduces the light transmission. The framework structure can be made of wood or metal which is necessary to hold the film in position in order to prevent it from flapping in the wind from the greenhouse [209]. The films can be attached to wooden framework structures with metal nettings or wire strands to form light-weight constructions that can be used in regions where there is no heating for during early growth or where wood is cheap. Metal frameworks are usually consist of galvanized metal tubes with hoops, ridge pieces, diagonal braces, and foundation tubes for receiving the ends of the hoops. The assembly of the metal framework is quickly carried out. Tensioning wires are also fitted, and the entrances at the two ends are of timber construction. The film is stretched over and secured to the framework, the edges being buried in a shallow trench running alongside the structure. The structure frames clad with PVC must be firmly closed at night to keep the heat in and so that during the flowering period good ventilation can be maintained. The hoops are often made of PVC tubes and are connected with ropes. The hoops are set in steel tubes which are partially buried, the film used being LDPE [247]. The use of double-layer film coverings separated by an air space reduce the heat loss from plastic protective structures and hence reduce the cost of fuel for heating [199]. The distance between the layers should maintain a dead air space for maximum insulation. The double film reduces light transmission but since the structural strength is greater, fewer supporting members are required [248]. Air-supported greenhouses are usually semicylindrical structures, maintained in shape by using air pressure, often provided by fans [249] and have the advantage of not requiring structural supports, they have improved luminosity and can be accessed with mechanical equipment. However, the disadvantage of this structure is its collapse in the event of an electricity failure.

2. **Rigid plastic greenhouses** have the advantage of strength but are an expensive option and much less often used than film. However, they are popular because of safety compared to glasshouses. These constructions are generally based on using sheets of fiber-reinforced polyester, rigid PVC, or PMMA. These materials have been used for greenhouse structures of conventional glasshouse design with a metal framework structure. Because of the high coefficients of thermal expansion, PMMA and rigid

PVC must be fixed to the framework at a minimum number of points [205, 206]. The other option is twin-wall polycarbonate which offers exceptional energy saving where the greenhouse is heated. This is also used for the ends of large commercial greenhouses because of its structural integrity and thermal efficiency [250].

Fiber-reinforced polyesters – Their properties depend on the composition of the resin and the amount and distribution of the fibers. The composite composition determines the penetration of light as well as its mechanical and chemical properties. Thus, the use of tetrachlorophthalic acid increases the refractive index whereas the use of PMMA in place of styrene lowers the diffusion power and increases the transparency and stability of the product. Polyesters are slightly transparent to UV radiation and the penetration is further reduced or eliminated by UV absorbers. Transparency of reinforced polyesters to solar radiation is low and hence gives rise to a reduced temperature build-up. The greenhouse effect results from the opacity of this material to radiation emitted by the soil.

Rigid PVC – Its light transmission varies appreciably according to the used stabilizers and lubricants in their compositions. The opacity of transparent PVC sheet increases with exposure to outdoor weathering and the development of a yellow to dark brown color reduce light transmission to such an extent that replacement ultimately becomes necessary. Degradation is accelerated at those points where the sheet is in close contact with the supporting structure and consequently local hot spots are created. Rigid PVC must be fixed to the framework at a minimum number of points.

PMMA – This is a rigid transparent plastic material and has a high transmission to radiation and does undergo some yellowing on prolonged outdoor exposure but this can be reduced by the incorporation of UV absorbers. PMMA must be fixed to the framework at a minimum number of points due to the high coefficient of thermal expansion of the metal framework. The superior light transmission of PMMA does not exert a great effect upon the crop growth [205].

3. **Glasshouses** are the most traditional coverings used and may be constructed with slanted sides and straight sides. Aluminum–glass buildings provide low maintenance, are aesthetic and weather-tight structure. The ease breaking and the high costs are the main disadvantages of this type.

- (B) **Direct covers.** These are frameless low tunnels and are virtually unsupported row covers. Interestingly, if perforated films and nonwoven fleece are used plants can strongly grow under such direct covers even if they are holding up the protecting cover themselves. The film or fleece is generally several meters wide and is laid very loosely with the edges held down with earth. The covering films will then float in the wind and expand as plants grow (floating cover). Growth under direct covers is often very fast, and at low cost. The covering is generally perforated PE because it needs to be lightweight and allow the passage of water for irrigation and air for ventilation. These covers provide the

same function as low tunnels in that they act to conserve heat, prevent excessive transpiration, protect from wind and heavy rain, and exclude pests, but the level of protection is different because of the intrinsic ventilation and the absence of a frame. If the cover is made of a very fine mesh it will be particularly effective for excluding pests such as carrot fly but allow good ventilation and passage of water. The effectiveness of nonwoven covers alone and in combination with black/white and brown PE mulch on growth of squashes has been investigated [251, 252]. The effects of different combinations of spun-bonded fabric covers, perforated and unperforated PE microtunnels and black PE mulch on growth and yield of muskmelons, insect populations, and soil temperatures have been evaluated [253].

- (C) **Tunnels.** Low tunnels provide an inexpensive means of protection and are useful as covers for low-growing crops. The most widely used tunnels consist of double hoops with the film held between them so that it can be slid upwards to allow ventilation. The labor required for adjustment of the ventilation is the only disadvantage of this tunnel type. Tunnels with single hoops are set up by stretching the film out over the hoop and then burying the two edges. Ventilation is introduced simply by making holes in the sides, depending on the climatic conditions. Another method involves two films used over metal hoops that are fixed at the top by clips to a steel wire which is stretched along the length of the hoops. The plants can grow upwards between the two films by opening the clips. This type of low tunnel can be easily ventilated and maximum ventilation obtained by removing one of the films. Film coverings without the need for support can be used for semiforcing by employing perforated and permeable films. These give protection to early crops grown in the open in spring [195]. This type of covering has similar advantages to the low tunnels, i.e., earlier crops, better quality produce, staging of production, and protection against birds. The cultivation of different varieties of vegetables and crops in plastic tunnels has the main advantage that crops can be produced earlier than in the open, with improved yields, by protecting them against frost and wind [254].

Low tunnels or row covers could be thought of as an improved development from the glass cloche or structure frame traditionally used in market gardening, being much more efficient though. In fact, PE films has made row covering highly economic on a large scale. Small tunnels are much less expensive than greenhouses, but more expensive than direct covers, and essentially do the same job. They are highly effective in the right circumstances, e.g., for short-term cover of low-growing crops. Construction size varies, but essentially a simple frame of hoops, stakes, and wires supports a film covering to give a typical cross-section of 50 cm high and about 100 cm wide. The edges of the film may be buried in soil or pinned down. The restricted volume and access means that care has to be taken with ventilation to avoid overheating and high humidity by opening the tunnel when necessary. Consideration also has to be given to providing the plants with sufficient water. Obviously, the small size restricts the material that can be grown and very often the tunnel does not remain in place for the whole growing period of taller species. The film covering is usually PE,

essentially the same as used for larger tunnels. Similar tunnels on a smaller scale are also cloches and frames with rigid or semirigid plastic construction. Cold frames are also quite popular and can still be seen in nurseries. Plastics used include PVC and twin-wall polycarbonate.

Large tunnels are simply a particular form of construction in which a high level of control of temperature, moisture, ventilation, shading, can be achieved and suitable for tall-growing plants. Their structures can be made with simple tubular metal framing and a flexible film covering and this has been the most popular commercial approach. However, a great variety of constructions have been developed including inflated double-skin roofing, multispans houses, and the use of rigid or semirigid plastic end covering. The different requirements in different climates and for different crops include construction details such as the need to insulate the film covering from metal supports to avoid its local overheating, the need to avoid anything that hinders the runoff of water droplets and the ratio of ventilation area to floor area.

Tunnel structures of LDPE, PVC, and EVA films can be used for semiforcing so as to grow without heating but with an increase in yield. LDPE and transparent plasticized PVC have comparable qualities regarding flexibility, lightness, and radiation permeability to short-wave light which penetrates into the interior of structures and heats up the soil and the plants. During the night, PE is equally permeable to the long-wave radiation emitted by the soil, thereby giving rise to a high thermal loss. PVC is impermeable to long-wave radiation, so that heat losses during the night are less and the temperature is therefore higher under PVC than under PE. However, with PE a temperature inversion becomes possible in the cooled region, i.e., lower inside a structure than outside. Thus, crops grown under PVC are earlier than those grown under PE. PEVAc film has improved permeability characteristics regarding radiation so that it competes with PVC in the production of early crops grown.

2.2.1.3 Nets for Plant and Crop Protection

An increase in the damage to plants and crops caused either by adverse weather or by birds has increased efforts for improved protection. Birds can be considered a pest in agricultural terms and the damage caused them can be excessive. In addition to potentially spreading transmittable diseases, birds can also damage and cause unsightly problems to fruit and vegetables. Protection of vegetables and fruit trees from bird damage is desirable especially before or upon ripening of fruits. There are various different ways that can be used to protect and control fruit tree from birds and the damage they can cause: (1) Chemical repellants are useful in fruit tree pest control, often helping to protect fruit trees from birds and while keeping other pests away. Pest control by the chemical repellants, e.g., by methyl anthranilate, must be repeated if the bird damage is continuing and after a heavy rain. (2) Electronic bird protection devices will keep the birds away from fruit trees by emitting a sound that frightens them. (3) Nets made from filaments of various polymers such as HDPE,

PP, and nylon are stretched over the trees to give the desired bird protection. Nets play essentially two roles in: (a) plant protection and (b) crop protection. The nets have effects on: fruit size and yields, fruit maturity and color, quality parameters, fruit sunburn and cracking [255–263].

- (A) **Plant protection nettings** are used as anti-bird and anti-butterfly nettings to stop pests on the wing and to protect plants against weather damage. In winter, the increase in the damage to plants caused by frost and winds presents a problem for loss of crop production that results in an increase in total crop costs, hence *antihail nettings* are used to protect plants against frost damage [264] and *shade and windbreak nettings* are very useful to provide wind resistance and shade. The increase in damage to crops caused by adverse weather has led to the use of *climatic protection nettings* as efficient tools for crop protection to prevent the loss of crop production that results in an increase in total crop costs. The effect of plant protection nettings on an orchard's climatic conditions (temperature, light, and humidity) [262, 265–271] can be explained by: (1) reduction in direct incident light and radiation by interception [255, 266, 272–275], reduction in maximum orchard temperatures [255, 266], increased minimum orchard temperatures, and increased humidity [276]. This indicates shading by the nets which lowers the temperature and the intense solar radiation as the main causes of sunburn and increases skin quality [265, 266]. (2) Air circulation interception that increases humidity and leads to decrease in plant water stress thus reduces irrigation needs due to decrease of evaporation. The shading resulting from the use of nets leads to: reduced number of fruits affected by sunburn incidence, decreased temperatures that decrease fruit cracking and favor appealing fruit color, decreased exposure to light leads to lower fruit sugar content [255, 263], and decreased photosynthesis caused by the interception of radiation results in reduced fruit size [266]. Increased shading leads to reduction of the radiation reaching trees, decreased soluble solid content of fruits, delayed fruit ripening, reduced fruit color due to the decreased direct sunlight on the fruits, and reduction of the evapotranspiration level. A reduction in plant water stress is favored by a reduction in maximum temperatures, increase in orchard humidity, and an increase in photosynthesis.
- (B) **Crop protection nettings** are used as crop gathering and fruit cage nettings to protect fruit and vegetables from both aerial raids and ground attacks from larger animals. Crop protection netting is also used as side netting on all manufactured fruit cages and is an ideal deterrent to birds, rabbits, and other similar pests, but has a large enough mesh size to allow invaluable pollinating insects to pass through. Heavy-duty protection netting of a high strength and durability consists of a high-quality square mesh knotted net, and a thicker gauge for superdurability. It can be used as a crop protection net on any fruit or vegetable cage, and used as any general-purpose garden netting. Fruit tree netting is lightweight, cost effective, and offers protection for fruit trees and gardens from birds and other predators. There are many different types of crop protection nettings: (1) *Crop-gathering nettings* can be used for the rapid

gathering of crops allowing the trees to be shaken without any great damage. Nets supports for fungicide or insecticide form a protective trellis which prevents mildew from the net growth stage of vines right up to leaf-fall [277]. (2) *Fruit cage nettings* will protect fruit and vegetables from both aerial raids and ground attacks from larger animals. High-strength and long-lasting knitted fruit cage nettings are used in the construction of fruit cage frames. (3) *Anti-bird nettings* are used for fruit trees to prevent the birds from reaching the fruits by trapping the birds. Wire can help to keep the bird control netting away from the fruits to prevent damage while providing adequate pest control. Anti-bird nettings can provide complete exclusion of birds over a long period of time and are of different mesh sizes and choosing the correct mesh size is important in order to prevent either large or small birds from getting inside the netted off area and becoming stuck or trapped. There are several types of netting available to exclude pest birds such as knotted PE netting manufactured using UV-treated flame resistant material that is long-life and heavy duty. Bird PP netting is strong, lightweight, and easy to install and used to protect crops and orchards from pest birds. This type of netting is ideal for use in homes, gardens, warehouses, airplane hangars, canopies, overhangs, and other large areas where pest birds are to be excluded. Bird control netting is used to: protect valuable crops from all kinds of pest attacks, repel the smallest of birds without trapping them in the net, and to repel small and large birds, animals, deer, rabbits, foxes, insects (including butterflies) and partially shield off wind.

2.2.2 Windbreaks

In exposed areas barriers against wind can have a significant effect on cropping. An artificial barrier against wind has obvious advantages over natural materials of consistent permeability. Windbreaks are used as barriers against wind for lowering the wind speed which reduces mechanical effects. Thus, they are effective as modifiers of the microclimate and have beneficial effects on the growth of plants. Windbreaks of plant rows of trees serving as shelterbelts have been effective in reducing wind erosion. Plastic snow fences have also served as windbreaks. Growing crops and postharvest residues can reduce wind erosion. Closely spaced crops are more effective than row crops. The establishment and subsequent growth of vegetation is crucial to stabilize dune areas. Sand dunes have also been stabilized with surface treatments, such as spray-on adhesives and soil stabilizers. Plastic windbreaks of PE or PP, essentially as meshes or grids supported vertically and fixed firmly between supports, are used in place of hedges, lines of trees, and bamboos [196]. The use of other forms of plastics for this purpose has been reported [213]. Adequate strength and stabilization against UV light of plastic windbreaks is essential. The inconvenience of these windbreaks is their cost of manufacture, maintenance, and the area lost for cultivation that provides a habitat for certain pests.

2.2.2.1 Benefits of Windbreaks

Windbreaks reduce the temperature of an irrigated crop and the vertical and horizontal transfer of heat, reduce the transfer of water from the plant to the air that leads to a reduction in the potential evapotranspiration, reduce the speed of the wind which is accompanied by a reduction in the amount of mechanical damage, lower the temperature during the night and reduce the air temperature of the irrigated crops that creates better conditions for plants growth, reduce the exchange of carbon dioxide and water vapor between the vegetation and the atmosphere that lowers the evapotranspiration, and hence increase the growth of plants and crop yields [215].

2.2.2.2 Mechanism of the Functioning of Windbreaks

When air meets an impermeable barrier it is directed upwards, and the width of the layer, as represented by the height of the windbreak, is reduced. Therefore, there is an increase in air speed and this reduces the pressure. Thus, air is drawn into the stream from downwind of the windbreak so that the air stream quickly regains its original dimensions and the static pressure increases. The air which is drawn into the stream thereby creates a turbulent zone immediately behind the windbreak. The flow of the air returns to ground level fairly quickly, so the area of the protected zone is relatively small. With a permeable windbreak the volume of air which is deflected over the top is less; consequently, the increase in speed is less and the pressure effects which lead to the formation of a turbulent zone are reduced. The deflected zone returns more slowly to its original course and hence the protected zone is longer. Thus, the wind speed can be less reduced as the porosity of the windbreak increases.

2.2.2.3 Factors Affecting Windbreak Protection

Various factors influence the efficiency of windbreaks, i.e., the efficiency of soil protection provided by a windbreak depends on: the permeability of the windbreak over the entire height of the films or sheets i.e., the effect of air flow through a permeable windbreak, the roughness of the smoother ground in front of the windbreak, successive windbreaks located behind another over a shorter distance, the climate of the used windbreaks region, the extent of the wind speed.

2.2.2.4 Soil Erosion

Loss of soil structure is often associated with a reduction in organic matter, which can reduce the resistance of soil to erosion. Thus, soil erosions due to the low capacity of topsoil to retain water are mainly due to the low content of organic matter in the topsoil. The organic matter in soil has a particle-aggregating effect, which

converts dust into heavy clumps [278–283]. Soil erosion is one of the most serious natural environmental problems, especially where arable land resources are limited and light and poor soils are present. Soil erosion involves physical detachment and removal of soil materials from one place to another and represents a primary source of sediment that pollutes streams and fills reservoirs. The two major types of erosion are geological erosion and accelerated erosion. (a) *Geological erosion* involves long-term soil-eroding and soil-forming processes and generally maintains the soil in a favorable balance having caused the many topographical features on Earth. Such soils are usually suitable for the growth of plants. (b) *Accelerated erosion* results from human or animal activities from tillage and removal of natural vegetation that leads to a breakdown of soil aggregates and accelerates removal of organic and mineral particles.

The major factors affecting soil erosion include: (1) Climate conditions: humidity, temperature, wind, solar radiation, precipitation. (2) Soil characteristics: soil structure, texture, organic matter, water content, clay mineralogy, density, as well as soil chemical, biological, and physical properties which affect the infiltration capacity and the extent to which particles can be detached and transported. Soil detachment increases as the size of the soil particles or aggregates increase, and soil transport rate increases with a decrease in the particle or aggregate size. Clay particles are more difficult to detach than sand, but clay is more easily transported. Tillage is intended to provide an adequate soil for preparing a seedbed and water environment for cultivated plants and reducing weed competition. Excessive tillage can damage soil structure, leading to surface sealing and increased runoff and erosion. (3) Vegetation results in reducing erosion by the effects of: (a) interception of rainfall by absorbing the energy of the raindrops and thus reducing surface sealing and runoff, (b) decreasing surface velocity, (c) physical restraint of soil movement, (d) improvement of aggregation and porosity of the soil by roots and plant residue which protect the surface from raindrop impact and improve the soil structure, (e) increased biological activity in the soil, (f) transpiration, which decreases the amount of soil water, resulting in increased water storage capacity and less runoff. (4) Topography is the degree, shape, and length of slope, size, and shape of the watershed. However, the most common factors for soil erosion of the accelerated erosion type are water and wind.

- (A) **Water erosion** is soil detachment and transport of the detached sediment resulting from the impact of raindrops or water flow directly on the particles of the soil surfaces. Raindrops break down and detach soil particles and the detached sediment can reduce the infiltration rate by sealing the soil pores, which increases runoff and sediment transported from the field. The impact of raindrops increases turbulence of streams, providing a greater sediment-carrying capacity. The soil losses by water erosion (eroded soil) reduce the productivity of irrigated soils, the crops yield, and the quality of the produce due to a decrease in the amount of water available to the plant, which can be overcome by higher fertilization. Sediments from erosion are the most serious pollutants of surface water and can deposit in streams and lakes and alter

stream channel characteristics and adversely affect aquatic plant and terrestrial life. The erosion effects of water can be minimized by mechanical control, varying the employed irrigation technology, reducing the water flow rates, by waterway vegetation or lining by concrete, stone, or plastics. These factors decrease the ability of a water flow to detach and move soil particles along surfaces, and increase the resistance of the soil surfaces to the force of the water flow.

- (B) **Wind erosion** causes soil movement by wind turbulences that damage land and crop plants. The eroded dust in the atmosphere is harmful to human health, specifically affecting the human respiratory tract. The quantity of soil moved is influenced by the particle size, density, gradation, wind speed, direction and distance across the eroding area. Surface encrusting caused by wetting and drying will reduce wind erosion for most soils as does an increase in the amount of plant residues. Tillage reduces soil water and wind erosion thus decreasing soil erodibility and increasing surface roughness. Water conservation in agricultural use is favorable for soils as it increases surface roughness and reduces runoff.

2.2.3 Polymers in Crop Preservation and Storage

A wide range of polymeric materials are used in packaging of agricultural products (fruits and vegetables) such as plastic crates and boxes that are produced from various polymeric materials for food and agricultural produce handling [26]. A wide range of trays, crates, and product boxes, molded from polymeric materials such as PP and HDPE are available. Thin PP sheets with folding qualities are being used as a replacement for carton board in packaging. Strong, ventilated crates may be produced economically for harvesting, handling, and transporting agricultural products of fruits and vegetables. Boxes produced from PP material are suitable for cut flowers since they provide good protection for the blooms. Boxes are also produced from structural foam material as HDPE reinforced with glass fiber. A system has been developed for producing and circulating collapsible and reusable plastic crates such as PP to replace traditional cardboard and wooden crates for transporting fruit and vegetable products. Despite their light weight, these containers that are compatible with standard container specifications are capable of holding a high load of produce and can be easily stacked. Films are extensively used for the packaging (preservation and storage) of vegetable and fruit products for direct sale to the consumers. The most common form of produce wrapping is that of stretch wrapping using highly plasticized PVC. The film is wrapped around the produce contained in a tray (formed from expanded PS sheet) by stretching over the pack and sealing on the underside. Films used for shrink wrapping are usually plasticized PVC, PE, or PP for packaging of vegetables and fruit. The technique requires that the film is applied directly to the produce, and then passed through a heated tunnel when the film shrinks and holds the produce firmly in position. The degree of shrinkage

depends on the amount of orientation introduced into the PE film at the manufacturing stage. Storage of fruit may be greatly improved by using wrappings and sacks with diffusion windows. These wrappings make use of the selective gas permeability of PE films and special silicone elastomer membranes so that the fruit is kept in a controlled atmosphere with optimum concentrations of oxygen and carbon dioxide. Plastic wraps have been used to protect tree trunks against damage by freezing, sun, and animals [211].

2.2.3.1 Polymers in Protection Against Pests

Various types of covers can be employed against birds, but for shielding off small flying pests one needs to use fine mesh as direct covers for exclusion to be effective. Insects can readily infest greenhouses and low tunnels. In fact one of the problems of using plastics for protection is that the conditions suiting the plants also suit the pests. Red spider and whitefly, for instance, are usually more of a problem under cover than in the open, because the closed environment of a greenhouse supports their development. The use of mulches in repelling insects can be highly effective. While netting is widely used to protect fruit, particularly soft fruit, from birds, polyolefin nettings with suitably small mesh size are being used attached to a frame forming a cage and covering the plants for protection against flying insects. Netting is also used on a small scale to protect fish in ponds from herons. Spun-bonded fleece used as wind and frost protection can also be effective in keeping insects out. PEVAc can prevent insect attack by interfering with insect behavior [284]. Effective tree guards can be made from recycled PVC and used in tree plantations [285].

Protective sleeves. Thin-gauge pigmented blue PE film sleeves have been introduced as a loose covering for protecting banana bunches during the growing season. PE is preferred to flexible PVC because of its lower price; the covers are used for only one season. An unusual application of PE sheet is to apply it as a sleeve around trees to prevent mealy bugs from climbing up [286].

2.2.3.2 Polymers in Shading

Shading can be achieved either with pigmented films or PE mesh screens on either the interior or the exterior of greenhouses. Black PE film mounted in the form of an easily movable tunnel is used to control the day length in cultivation out of season. Several techniques mainly using film have been used as shading to protect a cultivated area from excessive sunshine. A low-cost and easily erected shaded area can be made by tying pieces of black PE sheeting to strings or wires stretched above the crop. Shading is mostly important in exceedingly hot countries to prevent plants from becoming overheated. The use of porous mesh in tropical conditions can allow the cultivation of a broader range of vegetables. It has also been used to help establish newly planted areas in parks in tropical areas. Nurseries without natural shade can protect their stock with shade netting. Such artificial shading material has all the

advantages over natural shading, and it can be employed temporarily by season. Even in temperate climates protection is needed for shade-loving plants such as ferns and rhododendrons in nurseries. Greenhouses are often shaded with “paint,” the use of netting, or various blinds. Applying different degrees of coverage by netting and choosing appropriate colors it is possible to cater for different conditions and even different plants. PE shading netting and fabrics give coverage with a large variety of colors and are treated to prevent rotting and to repel insects [287].

2.2.3.3 Polymers in Harvesting and Crop Storage

Polymers are employed in crop harvesting in the form of containers: nets, bags, and crates. Their advantage over traditional materials is light weight and ease of cleaning and disinfecting. Plastic crates can be molded to particular forms to suit the crop and are reusable. The containers used at harvest are in many cases suitable for transporting the crop to store or market without damage. Film can be used in several ways for the storage of grain to line existing pits or silos, cover sacks stacked on a dry base or to directly produce storage containers, depending on the low permeability to air and moisture and low cost. The use of film as a covering for sacks in the open is expedient in times of exceptional harvest. Recently, there has been a large increase in the use of PE bags for grain storage [288]. The bags are essentially tubes in which the grain can be stored outside and alleviating the problem of limited on-farm storage at low cost. The trend for plastics to replace metals applies to conventional grain silos and here consideration has to be given to the electrical insulating nature of most polymers and the danger of dust explosions. Ensilage is an anaerobic fermentation process of storing and fermenting green fodder in a silo that requires air-tight containment for fodder preservation (silage). The object is to produce a material when a crop is plentiful that can be stored for feeding in the winter when food is scarce. Ensilaging has been carried out in steel or concrete structures, a difficult and expensive process. The other method of preserving fodder is by making hay which is seriously reliant on the weather or by introducing plastic film containment for silage to replace hay making. Haylage is made by essentially the same process as for silage but the grass has been allowed to dry before being baled and is wrapped in the same manner as silage. Initially, large bags were used while stretch wrapping now serves for large bales [289]. PE film is most commonly used but it has relatively low air permeability; thus, coextruded materials are being used which improve the permeability. The color is usually black but sometimes white or a black/white bi-extrusion is used, particularly in sunny climates. A white film outwards reflects light and helps avoid extreme heating of the fodder.

2.2.3.4 Polymers in Containers and Packaging

A wide range of shapes of plastics are allowing an enormous freedom in design and performance of agricultural containers and packaging. This applies to containers for

plants and seeds, troughs, pans, and buckets, packaging for fertilizers and plant protection chemicals, packaging of foodstuffs, tanks, and pits. PP plant pots in a large range of sizes are lighter than clay pots with considerably more efficient drainage. Their low cost and convenience are ideal for containerized plants that can be marketed and transported at any time of the year. Plastic pots serve for carrying and shuttling market tray systems for transport and display, having relatively high rigidity but low material usage. There are also specialized containers for the relatively new market of plug and young plants. Simple seed trays have been augmented/replaced with multicell plug trays and tray insert systems that cater to all possible plant raising needs. Plant containers are made in a variety of designs and sizes and have enabled container gardening under conditions of limited space availability at relatively low cost. Specialist containers have been developed for strawberry towers, hanging baskets, pond planting baskets, and potato growing. A variety of simple plastic buckets are used as troughs, pans, and drink-and-feed dispensers in animal husbandry. In domestic use, polyolefin compost bins, water butts, and watering cans are extensively used. Large carrying bags of PP or PE are used for horticultural rubbish and to package fertilizers, composts, soil improvers, lawn sand, providing efficient handling with good protection at low cost. Additionally, compost-filled grow-bags used for vegetables offer a pest- and disease-free starting environment. In agriculture, most everything nowadays comes in packaged form, including shrink-wrapped film that encases the pallets of bags of potting or seed compost and the foam to protect farm machinery parts during transit. Produce shipped by the agriculture industry after processing will in most cases be packaged when route to the retail market. Food packagings are highly sophisticated now; multilayer films with selective gas and moisture permeability suit the requirements for preserving any particular product. Milk, vegetable oils, and fruit juices sold in markets no longer come in glass bottles but usually in plastic bottles. Perhaps upsetting to the purist, plastic corks are now being used for sealing wine bottles and it has been demonstrated that screw tops with plastic insets are even more efficient. As an indication of the care taken with packaging, PE has been proven to be the best option for maintaining the taste and quality of produce [290]. Animal waste can be channeled from buildings and contained in GRP tanks or polymer-lined pits/ponds constructed as reservoirs. Tanks made of plastic or glass fiber-reinforced polymers and lined with PVC can be used in fish farms [291].

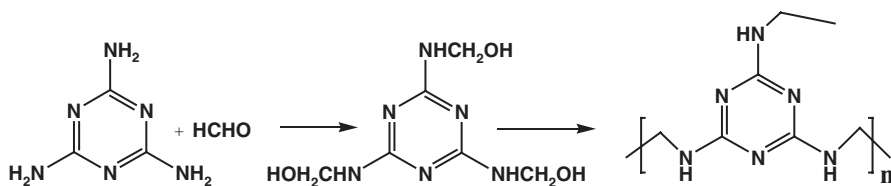
2.3 Polymers as Building Construction Materials

In addition to the utilizations of polymeric materials in plantations and crop and plant protection, they are also successfully used in agricultural building constructions [234]. They are utilized as engineering structural components for farm buildings and agricultural machinery and other engineering tools and operations. The successful applications of polymeric materials as structural components in buildings include: (a) farm building constructions such as wire and cable covering, as

moisture and vapor barriers, thermal insulation, pipe work and fittings, adhesives, sealants, siding materials, roof lighting, tub and shower enclosures, as paints for protection of traditional substrates, polymer cements, concrete reinforced by polymers, suspended roofs, (b) semipermanent structures such as animal shelters, silage containers, equipment shelters, (c) plastic tubing for use in the dairy industry, collecting the sap of maple trees, heating and ventilating livestock barns, (d) liners for water impoundments and canals, (f) plastic pipe for water transport and control in above- and below-ground use in irrigation and drainage.

2.3.1 Polymers in Farm Buildings

Polymeric materials are widely applied in building and construction operations. This transformation from traditional materials due to economic and demographic changes has created increased opportunities for polymers products [292–296]. The use of polymers for protective structures in animal and farm buildings is often in association with other materials such as concrete, steel, wood, and aluminum. Polymers often replace glass, brick, ceramics, iron, steel, and wood. The high potential of polymeric materials for use in construction is the rapidly growing market for various building parts replacing traditional building materials, as by resident consumer request. Polymers are used in a wide range of farm building construction applications, such as extruded gutters, siding, imitation wood beams, room dividers, window and door frames. Polymeric materials used as structural components in agricultural settings must have the property to withstand external mechanical load influences, i.e., possess good mechanical strength and stiffness. This behavior is primarily determined by the microscopic structure at the molecular level, i.e., by the macroscopic response to physical, chemical, and mechanical properties. All classes of polymeric materials such as plastics, elastomers, coatings, fibers, and water-soluble polymers have been utilized in this area of agricultural applications. In the construction of farm buildings, metal roof sheeting shows signs of deterioration after short periods due to condensation of water vapor produced by animals. Hence PE sheeting can be used to provide relatively cheap farm buildings, particularly animal shelters. HDPE and PVC have been used in rigid piping and tubing, in sanitary sewer lines, storm water lines, and potable water mains. Unsaturated PEs, PS, and PVC are other significant plastics predominantly used as construction materials. PVC is also used for siding, accessories, windows and doors. The thermosets of urea-, melamine-, and phenol-formaldehyde resins (Scheme 2.1) are used for resin-bonded woods such as plywood, particle board, and oriented strand board in buildings. Agricultural buildings can incorporate plastics in a number of ways which include PE damp-proof materials, PVC cladding, rainwater goods, and PU foam insulation. Plastic wall linings are easily cleaned and nonabsorbent and hence hygienic for wall linings in milking parlors. PVC has been found to be a practical and cheap option for flooring because of corrosion resistance and strength, not causing damage to stock, and ease of cleaning and disinfecting [291]. Foam mats from



Scheme 2.1 Formation of melamine-formaldehyde resins

recycled polyolefin have been shown to nicely serve as creature comforts to milk cows when used to cover floors [297]. PVC has been shown to resist kicking of horses when used as separating walls in stables.

Glass fiber made from spinning of molten glass, as reinforcing material impregnated with polymer as epoxy resin are used in the preparation of glass fiber-reinforced polymer composites, which improve the mechanical properties of the resulting reinforced polymer. Glass fiber-reinforced polyester sheets have a long service life and are unaffected by acids and alkali solutions and used as cladding materials in pressure tanks to provide the highest strength composition. Glass fiber-reinforced epoxy resins are used to produce structural panels. PU and PS foams are used in laminated panels between two layers of a surface material such as plywood. Glass reinforced-plastic bars are used in place of steel bars in reinforced concrete.

There is an important interrelationship between material selection, processing (convenience, design), and performance (shape, appearance, durability, quality, and cost). The acceptance of polymeric materials application in the construction of agricultural buildings over traditional materials is due to the following advantages: (a) *Processing*: the opportunity of optimizing the design of products; convenience of fabrication: (one-step process). (b) *Performance*: according to macromolecular properties and characteristics; convenient and inexpensive due to light weight, ease of use and handling; pigmentation and appealing appearance; elimination of repeated painting; durability and stability due to resistance to degradation and low maintenance requirements. In summary, the successful application of polymeric materials as components in farm building includes: ceiling and roofing, flooring, windows and siding, pipe work and fittings, thermal insulation (wire/cable covering, thermal barriers), polymer-impregnated concrete, polymer-cement-concrete, polymer concrete, reinforcing steel in concrete, building soil stabilization.

2.3.1.1 Ceiling and Roofing

Ceiling panels are fabricated from moisture-resistant polymers that can be used as a protective film over conventional ceiling tiles. Polymers have a distinct advantage over competitive materials because of their low density, moderate cost, ease of pigmentation, and low energy requirement in fabrication into final products. Polymer films are widely used for waterproofing purposes in building insulation as damp-proof membranes and vapor barriers. The basic parts of a roof are the deck, the

thermal insulation barrier, and the impervious roofing membrane that seals the roof complex structure. The built-up roofing membrane is made of (a) bitumen or asphalt, (b) the roofing felts for reinforcement, and (c) the aggregates for protection of bitumen against UV light and oxidation. The molten asphalt used for waterproofing is a mixture of mineral fillers and bitumen. The physical and mechanical properties of bitumen can be improved by chemical treatment and blending with rubbers or polymers. There are various polymer-bitumen mixtures, such as PE-bitumen, poly(styrene butadiene)-bitumen. Waterproof roofing membranes based on elastomer-bitumen mixtures especially preferred in cold climate and other materials such as PEPD, chlorosulfonated PE, and plasticized PVC are commercially used in roofing systems, depending on their ease of installation and handling, their durability, and resistance to weathering, chemicals, and ozone.

2.3.1.2 Flooring

A number of polymers are used as flooring materials, such as PVC tiles, PVCVAc, vinyl-asbestos tiles, PVC welded sheet, fiber-epoxy polymers, PP, and PU. All are inexpensive materials for use in flooring applications. Polymeric materials applied as domestic floor surfacing materials, where appearance and glazing are necessary, provide other advantages as being easily installed, durable, lightweight, flexible, slip and dent resistant, scratch and scuff resistant, stain and dirt resistant, fungus resistant, heel-mark resistant, exerting superior chemical resistance, and having decorative effects for seamless floors. However, for industrial floors where appearance is not critical, sanding and glazing are not necessary. Laminated PVC products made of several sheets of varying thickness are widely used as flooring materials, offering a wide range of colors and patterns, ease of cleaning, good cushioning, insulation, and reasonable price. PP flooring provides heavy-duty, easily cleaned work platforms, increasing operator comfort and safety, and resistance to corrosion and bacteriological attack. Epoxy flooring is used only for industrial flooring purposes due to its low level of sound insulation and lack of pleasing appearance. Epoxy flooring systems can be used as floor coverings over a subfloor of concrete, wood, or steel, and can also be used for remedial work and applied over existing floors. PU flooring can also produce durable, attractive seamless floors and imaginative effects by embedding a variety of different colored fillers into the PU resin.

2.3.1.3 Windows and Siding

Window frames are usually made of PVC formulations with PEVAc, chlorinated PE, or acrylic exhibiting the particular requirements of impact strength and weathering resistance needed under conditions of different climates. Bonding of acrylic to PVC allows window production with a wide range of colors and designs. Both production and precision in window extrusion have been improved with the development of new screw designs, better dies, and microprocessor control of production

parameters. PVC is used widely as siding for houses, competing with wood and aluminum. It can be extruded as siding in long, uniform panels as required, and either applied directly over sheathing in new construction or over deteriorated wood siding. Resilience of PVC siding minimizes damage by impact and stability to biodegradation especially in humid areas, which is another advantage of PVC siding. The insulating value, the relatively low cost, and the simple installation are all in favor of polymers over competitive materials in this application. The technology for producing self-frosting glass windows depends on a liquid crystal polymer film that is produced by dispersing liquid crystal droplets in a polymer matrix sandwiched between two conductive-coated polyester films. The film allows for windows that can be either frosted or cleared on demand. To clear the window, one flicks a switch, which causes the crystals to “line up.” To frost the window, the charge is broken, thus returning the crystals to their random, unaligned state. An optical film has been designed to be used in windows to create a reflecting screen capable of returning the image like a conventional mirror, while preserving the transparency and visual properties of glass. It consists of a single-layer film with a polyester base of high optical quality, i.e., treated for UV rays, on which aluminum oxide particles of controlled density are deposited using a complex vaporization process and a second polyester crystal layer to protect the metal coating. The film is coated with a UV-resistant and pressure-sensitive acrylic adhesive that can be reactivated in water. Once applied to the window, the film becomes an integral membrane, forming an authentic laminate.

2.3.1.4 Pipes

The main factors contributing to acceptance of use of plastic pipes in buildings include their low cost relative to conventional materials, excellent corrosion resistance, and ease of installation. Plastic pipes are fabricated from PVC, PE (principally HDPE), PP, chlorinated PVC, polybutylene, ABS terpolymer, and other polymeric composite materials such as fiber-reinforced epoxy and polyester. Perforated drainage pipes are not as fragile as ceramics, and long pipes can be extruded easily. Cutting into desired lengths is easy and joining is relatively simple. However, in those applications in which the pipe must withstand high pressure, metal pipe is still superior.

2.3.1.5 Insulation

Major uses of insulation in the construction industry are in roofing, residential sheathing, and walls. In these applications, polymeric foams offer advantages over traditional insulation such as glass fiber, and these include higher insulating value per inch of thickness and lower costs. The use of polymeric foam for insulation increased markedly due to increased awareness of the need for energy conservation. Foams are available as rigid sheets or slabs which are used in the

majority of roofing systems, as beads and granules which are used in cavity wall insulation, and also as spray and pour-in applications. PU foams, particularly polyisocyanurate products and expanded PS are used on commercial scale. PS foam holds much of the sheathing market. In masonry and brick walls, PS foams are mainly used because of their better moisture resistance. In cavity walls, loose-fill PS is used, while exterior wall applications use low-cost expanded PS. PU–polyisocyanurate products are the leading products in plastic foam, as sheets and slabs and have higher insulation value and good flammability ratings. A shift toward single-ply roofing as compared to built-up roof systems has an important influence on the type of foam being utilized. Thus the lower cost of expanded PS has promoted its use in preference to PU foam and extruded PS in single-ply applications. This is facilitated by the fact that the problems of damage to expanded PS foam from hot pitch when used in built-up roof systems are not encountered in single-ply systems. As wiring insulation, PVC is favored because of its greater resistance to burning. Because of its flame resistance, it competes effectively as insulation for inside wiring, particularly in constructions where weight is an important factor.

2.3.1.6 Polymer-Modified Concrete

The improved useful physical and mechanical properties of concrete in addition to the corrosion stability of reinforcing steel are the main reasons for the continuous interest shown in polymer-modified concretes. Polymer concretes are materials obtained by the addition of monomers, prepolymers, or polymers to conventional concrete, either during the mixing process (premixing) or by impregnation of the mature concrete (postmixing). The addition of polymers will lead to improved mechanical properties, in particular regarding durability of the concrete and its ability to prevent corrosion of the reinforcing steel. There are the following polymer–concrete composite types:

- (A) **Polymer-impregnated concrete** is composite prepared by impregnating dry precast Portland cement-concrete with liquid monomer and polymerized by radiation, thermally, or chemically. Some of the most widely used monomers for this type of cement composite include: MMA, S, BA, VAc, AN, MA, and TMPTMA as crosslinking agent. With impregnation by an appropriate monomer, the main effect after polymerization is the filling of the continuous capillary pore system, which reduces the porosity. The reduction of porosity reduces the effect of stress concentrations from pores and microcracks, thereby increasing the strength of the composite. The largest improvement in the strength and durability properties obtained with this composite is strongly dependent on the fraction of the porosity of the cement phase that is filled with polymer. It exhibits an increase in the compressive strength and the modulus of elasticity, reduction of the water and salt permeability, improvement of the freeze-thaw resistance, and zero creep properties. The film

already formed by curing on the surface retains its moisture necessary for full hydration of the cement. The improved specific characteristics of this composite material place it in a position between traditional concrete and other groups of engineering materials as metals and ceramics. The important applications of polymer-impregnated concrete composite are in pipes, underwater habitats, dam outlets, and underwater oil storage vessels. The attractive property of blocking the pores in the concrete and restricting the permeability of moisture and oxygen not only prevent corrosion but also increases the wear resistance of the resulting concrete. Incorporated polymer has been used to improve the durability of concrete, to make the concrete behavior more ductile, and reduce short-term deflections because of the increased elastic modulus and the reduced creep. The improvement in properties that can be achieved depends on the initial quality of the concrete and the amount of impregnated polymer. Polymer impregnation increases the shear capacity of beams without shear reinforcement. Although styrene is an attractive candidate for properties and economical reasons, MMA is preferred because it polymerizes readily and is a suitable impregnating material. TMPTMA and DAA are better suited for high temperature applications. Components of such materials are suitable for underwater structures, desalination plants, bridge decking, and concrete pipes for high pressure gas.

- (B) **Polymer-cement concrete** is a modified concrete in which a part of the cement binder is replaced by organic polymer. It is produced by incorporating a monomer, prepolymer, or dispersed polymer latex into a cement-concrete mixture. The process technology used is similar to that of conventional concrete and has the advantage that it can be cast in place for field applications. Most of the polymer-cement-concrete composites are based on different kinds of lattices obtained especially by emulsion polymerization. The lattices are aqueous emulsions containing polymer particles such as SBR, NBR, PVAc, copolyesters of AA-MAA, and PAA-PMMA-SBR. The compatibility of SBR, PVAc, and acrylic lattices with Portland cement produces particular characteristics that led to wide use of this component as polymer-concrete composites.

The polymer latex used for making a polymer-cement-concrete must be able to form a film under ambient conditions, coat cement grains and aggregate particles, and form a strong bond between the cement particles and aggregates. Polymer-cement-concrete has a higher corrosion resistance as compared with ordinary concretes and can effectively be used for floor coating in a moderately aggressive atmosphere, at milk-processing factories and breweries. However, the presence of cement in polymer-cement-concrete is a source of corrosion destruction under the action of more aggressive and concentrated chemical media at sugar refineries and meat-processing enterprises. In such cases, polymer-cement-concrete may be recommended only for under floors. The problem may be radically solved by producing floor coatings with a purely polymeric binder. For example, the use of epoxy alkyl resorcinol-based polymer concretes for floor coatings in production shops at food industry enterprises

increases the corrosion resistance of the floors to a great extent [298]. Reinforcing conventional concrete with PP filaments has been used for concrete pile shells where resistance to breakage drastically reduces down time and costs. The material results from the addition of PP filaments to foamed-concrete is easier to handle, resists frost damage, has better aggregate distribution, and can be decorated with three-dimensional effects.

- (C) **Polymer concrete** may be considered as an aggregate filled with a polymeric matrix without any cement, i.e., it can be described as a concrete containing polymer as a binder instead of conventional cement. The aggregate of small particles is used in producing polymer concretes to minimize void volume in the aggregate mass so as to reduce the quantity of the polymer necessary for binding the aggregate. Aggregates commonly used include quartz, silica, fly ash, and cement. Thus, by careful grading, it is possible to wet the aggregate and fill the voids by the use of a some polymer and to obtain high degrees of packing with high compressive strength. A wide variety of monomers, prepolymers, and aggregates have been used to obtain polymer-concrete composite such as epoxy prepolymer, unsaturated polyester–styrene system, MMA, and furane derivatives. To obtain the best chemical resistance, complete curing of the polymer is necessary by using an appropriate crosslinking agent. In order to improve the bond strength between the macromolecular matrix and the aggregate, a silane coupling agent can be added to the hydrophobic monomer before the polymerization process. The nature of the aggregate influences the hydrothermal stability of polymer-concrete composites.

The product of the mixture of unsaturated polyester with fine aggregate has higher compressive strength and bonding strength than conventional concrete, permitting thinner and lighter components. The applications of this material include: boundary markers, windowsill units, drainage gullies, effluent pipes and sumps in chemical plants. The products of PU foam and unsaturated polyester foam which fill the spaces between aggregate particles of expanded glass and clay aggregates offer fire resistance materials that are used in prefabricated pod bathrooms and external wall panels. Polymer-concrete composites based on unsaturated polyester and wet aggregates of cement and silica result in significant strength improvements. The chemical bonding between cement particles and carboxylate anions of unsaturated polyester brought on by a hydrolytic reaction is a crosslinking reaction. The addition of MMA to unsaturated polyester–styrene provides a hard, clear mirror finish, improves the workability without reducing the strength, and enhances durability. Polymer-concrete composites offer several advantages such as fast curing, impermeability to moisture, very little cracking of the concrete caused by freezing and expansion of moisture within the cured mix, resisting salts and other agents that cause corrosion of the reinforcing steel within the reinforced concrete. These properties have led to the use of polymer-concrete composites in water treatment and sewage treatment plants. They can be used in thinner layers than conventional concrete to give the same strength at lower volume, thus allowing a weight and cost

reduction. The excellent resistance to chemicals allows many applications in the construction of sewer systems, sewage treatment plants, animal stables, and high-resistance floors.

2.3.1.7 Steel-Reinforced Concrete

Corrosion of the reinforcing steel in conventional concrete by moisture and oxygen is a very costly problem in the construction sector. This corrosion problem can be solved by the use of polymers which fill the pores in the concrete, restricting the permeability of moisture and oxygen that cause and accelerate the steel corrosion. The successful application of epoxy coatings on underground transmission pipes has received considerable attention, and fusion-bonded epoxy-coated reinforcement can significantly extend the durability before deterioration of reinforced concrete with uncoated steel bars in areas with a high level of salinity. Epoxy-coated reinforcements have shown relatively little steel corrosion and concrete deterioration in structures of service [299], while in other cases there has been unsatisfactory performance of epoxy-coated reinforcements in regular maintenance, where the coating was found to be completely disbonded from the steel. Epoxy coatings are effective in preventing corrosion of reinforcing steel in highly corrosive environments. These observations have brought into focus the need to study damage morphology in terms of coating characteristics, i.e., the adhesion, integrity, and thickness of coatings. If there are no defects, the corrosion protection barrier is effective, but if there are defects in placed epoxy-coated reinforcement, the coating resistance is disbonded from these defects. To improve the long-term adhesion of epoxy coatings to reinforcing bars other approaches need to be implemented which include chemical treatment of blasted steel surfaces prior to coating application, and developing a strong quality assurance for coating application industries [300].

2.3.1.8 Building Soil Stabilization

Building soils are the basic structural materials on which constructions are built. The design of a foundation depends on soil factors: the soil type, the soil layer thicknesses and their compaction, groundwater conditions. Soils consist of different layers with varying thicknesses and of different particle sizes (clay, silt, sand, gravel, and rock). The voids between the larger particles are entirely filled by smaller particles. The finer grained soils become fluid when mixed with water and exhibit spongy and slippery characteristics and in a dry condition, clay becomes hard and impenetrable, silt becomes powdery. They exhibit elastic properties, i.e., deform when compressed under load and rebound when the load is removed. The elasticity of soils is often time dependent, i.e., the deformations occur over a period of time. Because of these properties, a building which imposes on the soil a load greater than the natural compaction weight of the soil can shift because the soil may settle in time.

Hardcore, aggregate bases or layers of drainage gravel, often to which polymers as polyester fibers are added, stabilize the soil and prevent objects from sinking into the subsoil.

2.3.1.9 Polymer Properties in Building Construction

The use of commercially available polymeric materials with their distinct advantages over other competitive materials in the building construction sector depends on their cost and their physical and mechanical properties. The properties of polymer used in buildings include: (1) *Physical properties*: the low density of polymers provides important advantages over metals and ceramics in those applications in which the weight-volume ratio is critical. Low density can be altered in the desired direction by various means. Polymers have a high tensile strength-to-density ratio, which allows reduction of the material mass, enabling to build strong structures of the least possible weight. Polymers have excellent dielectric properties, i.e., can be used for electrical insulation. Both the dielectric constant and the surface resistivity of polymers are influenced by moisture. For use in dielectric applications, water resistance filler is preferred to provide the best possible combination of properties for electrical wire insulation and cable jacketing. The ease of fabrication and flexibility of polymers are important factors favoring their use as ideal materials in rigid insulator applications. However, polymers have unfavorable electrical breakdown strength, so they are less widely used in high-voltage applications. In addition, polymers are good heat insulators, and have favorable features for sound proofing, and possess good optical properties i.e., are colorless and transparent, and are good adhesives. (2) *Mechanical properties*: many polymers have a high tensile strength-to-density ratio. However, some polymer composites have strengths well within the competitive range of metals and have the ability to damp mechanical vibrations. Polymers are usually materials of choice when low density and ease of fabrication are required but the high strength can be enhanced by the introduction of reinforcing agents which enable polymers to compete effectively with metals in certain applications. (3) *Morphology*: polymers exist in a semicrystalline state having advantages regarding strength in the ordered crystalline regions and flexibility in the disordered amorphous regions. Polymers can be applied in engineering solutions when strength is combined with flexibility, i.e., toughness, in the same copolymer or blend of polymers, or orientation of the polymer chains at the macrolevel to maximize strength in polymers. In general, polymers exhibit higher strength in tension than in compression. (4) *Processability*: polymer fabrication into final products in many processes requires less energy than the energy required for fabricating the same product from metals. Polymers have further advantages regarding ease of pigmentation and ease of fabrication as a result of their low melt flows that can be used to manufacture complex products with a high degree of detail, allowing workability and weldability. (5) *Deterioration*: vinyl polymers degrade when exposed to high temperatures or UV radiation, but they are resistant to breakdown by hydrolytic degradation and biodegradation by microorganisms. In contrast to metals, polymers are ideally

suited for applications in the presence of high humidity or moisture. Their high durability and corrosion resistance make them suitable for use in situations with required long service life in aggressive media, e.g., in underground structures, for water proofing various constructions, for making chemically resistant articles and structures. (6) *Scrap reuse*: the separation of recovered polymer scraps from waste stream mixtures can expand their reuse and remove some serious problems in respect to environmental pollution.

2.3.2 *Semipermanent Structures*

PVC and PE films have been used extensively for protecting silage stored in bunkers, trenches, and stacks. They are used as caps in conventional and trench silos. These polymeric films exclude oxygen from the anaerobic atmosphere developed by the fermenting silage, reduce spoilage losses, and maintain the palatability of the ensiled material [175, 176]. Silos have been constructed of flexible glass-reinforced polyester sheets bonded to PP [213]. PE and PVC sheeting is also used as cover for agricultural equipment, for harvested crops such as grain, and for other commodities that need protection from moisture damage. Plastic film and panels are used as building materials in rearing animals and poultry and for winter shelter or summer shade for livestock. Inflatable plastic structures and light-weight, prefabricated portable houses made of foamed polymeric materials have been used for temporary, seasonal storage facilities. For increased egg and milk production in environmentally controlled houses, foamed plastic insulation is used in farm buildings. Polymers have also been used in other areas such as: (a) *Growing trays and troughs*: potted seedlings are grown in trays carried on free-standing pillars in the greenhouse. Trays and troughs are molded from PP and HDPE and can be easily handled on trolleys for transporting. Double-wall PP-extruded sheet is light, rigid, and used for canal systems and for forming gullies lined with black PE film in cultivation. (b) *Baler twine* is a special application mainly based on PP; ageing has been improved by incorporating UV stabilizers. (c) *Animal protection* by small coats and jackets made from PE film especially for young animals (lambs) often required because of high losses by exposure to a combination of wind, rain, and excessively low temperatures.

2.3.3 *Polymers in Agricultural Equipment and Machinery*

Plastics are used for components such as covers and bearings in agricultural equipment. PP and nylon can be molded to give high strength components, while extruded sheet can be vacuum-formed to produce covers and boxes. The range of plastics and rubber-based components used in agricultural machinery parts includes polyamide gear wheels and bearings, PP and glass-reinforced polymer

covers, electrical wiring, and various synthetic rubber seals. The biggest use of rubber in agriculture is for tractors tires, which have large tires especially as the engine power has increased [301–303]. Polymers are extensively used in dairy equipment including hoses, storage tanks, and rubber liners. High impact PP is successfully used in lawn mowers, e.g., as an under deck to improve grass collection and reduce noise [304]. Spraying equipment uses PP tanks, rubber seals and many components are molded plastics. Polymers are prevalent in tools; PP has even replaced steel for the trays and wheels of some wheelbarrows with the obvious advantages of strength to weight ratio and no rusting. Plastics were increasingly replacing metals in engines of garden machines and that polyamide was being used in handles, as described in the review of lawn and garden injection molded products [305].

2.4 Polymers in Water Handling and Management

Rainfall distribution is geographically and seasonally extremely variable and in many areas there are periods in which the amount of water is insufficient for growing crops. The demand for water is increasing. Agriculture is the main consumer of water and only 50 % of water used in agriculture actually reaches the plants [306]. In consequence, proper water management for agricultural and horticultural use is of paramount importance. Clearly, water needs are greatest in arid regions but water can also be a limiting factor in temperate regions and using less water would reduce the needs. The use of plastic materials in irrigation technology has contributed to a real change in irrigation in many ways, from the actual irrigation equipment to the control of water by changing of soil characteristics [307]. Films, tubing, and reservoirs provide improved means for making water available to plants through: (a) water storage by reservoirs and lakes, the construction of dykes and the control of streams; (b) controlled distribution of irrigation water and removal of excess water by drainage. The adequate management of water in a most effective way can help to reduce environmental stress. Water conservation can be improved by increasing the rate of water movement into the soil by appropriate drainage and irrigation practices.

Plants need water and carbon dioxide along with sunlight for photosynthesis. Shortage of water in the soil and low insolation slow down photosynthesis. Crop yield depends also on the availability of minerals (fertilizer). The utilizable water available to the plant is the difference between the retention capacity of the soil and the limit of extraction, and this capacity is dependent on the type of soil. In arid zones, the water which is available to the plant is only a fraction of the water received by the soil because the latter ends up in different places, for instance, as runoff water, seepage water lost or diverted, or water which is a constituent part of the soil and is not extractable by the roots. If the water extracted by the roots is insufficient, the plant will wilt and may eventually reach the permanent wilting point. Each plant requires a certain depth of soil for occupation by its roots and the water

requirements must be satisfied for each period of plant growth, which depends on the season that determines the quantity of water required to the plant and the amount lost by evapotranspiration.

2.4.1 Water Types

The only practical source present for a continuous water supply for all agricultural, industrial, and domestic uses is rain which is the source of water for lakes and rivers. Desalination of salt water can supply water for high-value uses in some countries. Water problems, involving water distribution, and water demands by agriculture are continually increasing because of population growth and the necessary development of additional irrigated land. The development of water resources involves storage and transport of water from the place of natural occurrence to the place of beneficial use. Natural water sources are of three types:

2.4.1.1 Surface Water (Rivers, Lakes)

Surface water predominantly results from rainfall that continuously feeds streams, rivers, and lakes. Rainfall characteristics include: rainfall amount and intensity, the depth of rainfall, and the frequency of occurrence. Relatively high intensity and long duration result in a large total amount of rainfall that causes soil erosion damage and may result in devastating floods. Rainfall intensity varies greatly with geographic location and the duration of occurrence. Water from rainfall will infiltrate the soil and some will flow to runoff and stream channels, lakes, and oceans. Soils higher in clay will have greater runoff, whereas sandy soils have less runoff. The total annual runoff volume from storms is of interest when flood-control reservoirs are to be designed for irrigation or water supply. Waterways are often located where there is a low flow over long periods of time and they can be established by vegetation. If establishment is difficult because of poor soils or an adverse climate, organic fiber or plastic meshes with seeds in the fabric are used to improve germination by making more water available to the seeds and offers some erosion protection. Soil stabilizers and asphalt mulches assist in fixing the soil and increase channel erosion resistance. Accumulation of sediment in waterways may restrict channel capacity and the best method of minimizing sediment problems in waterways is by reducing erosion within the upland watershed. Sediment may deposit at the lower end of the waterway if the slope decreases. Accumulated sediment may be removed or the channel reshaped to minimize damage to the vegetation, and to prevent localized erosion.

2.4.1.2 Groundwater (and Wellwater)

Groundwater predominantly results from rainfall that has reached the zone of saturation in the bottom soil layer through infiltration and percolation. This subsurface water is developed for use through wells, springs, or dugout reservoirs. It is an

important source of water supply and is being withdrawn much faster than it is being replenished from infiltration and percolation of precipitation. Groundwater supplies may be at the soil surface near lakes, swamps, and continuously flowing streams, or primarily obtained from artesian wells, which are present when water is confined under pressure between upper and lower impervious layers. Wells are holes drilled downward from the soil surface into the groundwater aquifer. A casing is installed during the drilling process to stabilize the hole allowing water, but not aquifer particles, to move into the hole. The lower portion of the casing is the well screen. The openings in the screen should be properly sized to minimize the movement of sand into the well.

2.4.1.3 Wastewater

Municipal sewage contains oxygen-demanding materials, sediments, grease, oil, scum, pathogenic bacteria, viruses, salts, algal nutrients, pesticides, refractory organic compounds, and heavy metals. Several characteristics are used to describe sewage, which include: turbidity, suspended solids, dissolved solids, acidity, and dissolved oxygen. The cost of wastewater treatment depends on many factors such as plant location, environmental control regulations, and type of wastes produced. Overall costs can be minimized by utilizing professional services of highly qualified and experienced engineering firms. The capital and operating costs of wastewater treatment increase with increasing efficiency of required contaminant removal.

2.4.2 Polymers in Water Treatment

Water quality may be improved by the proper selection and management of the water sources and delivery methods. Water purity is determined by the presence of contaminants: (a) *Physical contaminants*: result from suspended sediment in irrigation and runoff water. Sediment occurs because of soil erosion and disposal of man-made objects. Sand may be obtained during pumping from wells. Sediment must be removed from water used in microirrigation systems to prevent plugging. Sands may cause excessive wear to pump impellers and to the nozzles in sprinkler irrigation systems. If sediment is deposited on sandy soil, the textural composition and fertility may be improved. Sediments derived from eroded areas may reduce fertility or decrease soil permeability. Sedimentation in canals or ditches results in higher maintenance costs. (b) *Chemical contaminants*: result from chemicals that enter the water supply from industrial processes and agricultural use of fertilizers and pesticides or introduced during water movement through geological materials. (c) *Biological contaminants*: result from microorganisms as bacteria and viruses that enter the water supply from human and animal wastes and can create serious health problems.

The natural water from rivers or wells and wastewater can be treated by several physical, chemical, and biological means to produce clear, safe, and tasty water that presents no hazards to the human and animal consumer. While river water may be

polluted with mud and bacteria, well water is often hard and may contain high levels of dissolved ions as iron and magnesium. The type and degree of treatment are strongly dependent upon the source and use of the water. The treatment of water is usually divided into three major categories: (1) *Purification for domestic use* in which water must be disinfected to eliminate disease-causing microorganisms. (2) *Treatment for industrial use*. For water to be used in boilers it must be quite free of salts because the minerals form deposits on heating and reduce heating efficiency. (3) *Treatment of wastewater* for agricultural reuse and wastewater being discharged into rivers may require less rigorous treatment. As world demand for water resources increases, more extensive means will have to be employed to treat water. The process of wastewater treatment occurs in three stages:

2.4.2.1 Primary Treatment

The first step in wastewater treatment is the removal of water-immiscible liquids and insoluble solid matter from the untreated wastewater by several physical processes via density separation such as screening, sedimentation, flotation, and filtration. Screening consists of the removal of large objects as well as grit, grease, and scum from wastewater. The removed solids are collected in screens and scraped off for subsequent disposal. Small-size particles as sand and other small objects may be separated by subjecting to settling under conditions of low flow velocity, and scraped mechanically from the bottom of the tank. This removal process may reduce the amount of particulate matter preventing their accumulation in other parts of the treatment system, reducing clogging of pipes, and protecting moving parts from abrasion and wear. Solid colloidal particles are removed by settling and filtration, whereas the solid suspended matter is coagulated by flotation with polyelectrolytes and the sedimented solids by aggregation are removed by fine screening. Dense suspended matter in wastewater can be separated by settling, while some other solids contain higher surface area relative to their density and thus float to the surface and can be skimmed off there. Air dissolved in wastewater under pressure and then released at atmospheric pressures is generally used to effect flotation of suspended solids. Sedimentation removes settleable and floatable solids by aggregation of flocculent particles (grease) for better settling by the addition of chemicals. Grease consists of oils, waxes, fatty substances, and insoluble soaps containing Ca and Mg. Flotation and sedimentation generally reduce the solids into sludge. Flotation requires less retention time than that required for sedimentation to remove solids. Screening is an economical and effective means of rapid separation of relatively large-sized suspended solids from the remaining wastewater.

Colloidal solids are small enough to remain stable, but interfere with the passage of light, and therefore cause turbidity. They do not settle unless destabilized and flocculated into larger masses with sufficiently high density by coagulants. (a) *Coagulation* involves the reduction of the electrostatic repulsion of the negative surface charge surrounding colloid particles via neutralization by binding with positive ions as *aggregating agent* which results in precipitation of aggregated colloids. This kind of aggregation

by neutralization of the surface charge on the particles results in precipitation. (b) *Flocculation* depends upon the presence of polyelectrolytes as bridging compounds, which form chemical bonds between charged colloidal particles and aggregate the particles in relatively large masses. The flocculation process induced by anionic polyelectrolytes is greatly facilitated by the presence of metal ions capable of forming bridges between the anionic polyelectrolytes and the negative surface charge surrounding the colloidal particles. Coagulants as normal electrolytes $\text{Al}_2(\text{SO}_4)_3$, or polyelectrolytes with a strong positive charge are added to stimulate coagulation and appear to react with the negative colloidal particles in the wastewaters forming clusters that settle out with gelatinous $\text{Al}(\text{OH})_3$ and can later be removed. The aggregation and settling of microorganisms (bacterial cells) is essential to the function of biological wastewater treatment systems for the removal of organic material and its oxygen demand.

2.4.2.2 Secondary Treatment

Because of the high pollution density of wastewaters by organic constituents, and the rapid industrial development for water, there is a great need to treat wastewater in a manner that makes it suitable for reuse. Organic constituents such as toxic substances, volatile solutes, and other odorous substances can be removed by several procedures: (1) they can be removed by air and steam stripping. (2) Dissolved oxygen in wastewater is suitable for microorganism degradation by biological processes that allow the biodegradation of organic matter. The waste is oxidized biologically under conditions of optimal bacterial growth which does not affect the environment. Wastewater treatment processes employ biological means by activated sludge, trickling filtration, rotating biological contractors, oxidation-pond treatment, or sorption by activated carbon. The organic contaminants removed by these processes include suspended solids and dissolved organic compounds. (3) Trickling filtration is a biological waste treatment process in which wastewater is sprayed over a solid medium (rock, plastic, or glass) covered with microorganisms for biological oxidation degradation of organic matter. (4) Rotating circular biological reactor consists of groups of large plastic discs (HDPE, PS) mounted close together on a rotating shaft, in which half of each disc is immersed in wastewater and half exposed to air. The discs accumulate thin layers of attached biomass that build biological growths on their surfaces, which degrades organic matters in the sewage by oxidation. The advantage of this process is its low energy consumption because it is not necessary to pump air or oxygen into the water. (5) Activated-sludge treatment consists of aerating biological flocculent growths within the wastewater. The surface for biological oxidation is created on the flocculent growths. Microorganisms in the aeration tank convert organic material along with nitrogen and phosphorus in the wastewater into microbial biomass and carbon dioxide, nitrate, and phosphate. Recycling of active organisms provides optimum conditions for waste degradation present in the aeration tank. This process is the most effective of all wastewater treatment processes. Oxidation-pond treatment is less effective, requires large land areas, long detention time, emanates odors, but is not expensive to build and operate.

2.4.2.3 Tertiary Treatment

Heavy metal elements and excess inorganic salts which are often contained in wastewater are potentially hazardous and can cause disease and discomfort, cause scale in pipelines and equipment, accelerate algal growth, increase hardness of water, and enhance metal corrosion. Water hardness is caused by Ca and Mg salts which are forming insoluble curd by reaction with soap that adversely affects detergent performance. Hard water causes formation of mineral deposits on heating units, coating the surface of hotwater systems, clogging pipes, and reducing heating efficiency. Inorganic salts can be removed by several processes such as ion exchange, membranes (reverse osmosis, hyper- and ultrafiltration), evaporation, and distillation. Water softening by removal of inorganic ions can be achieved by: (a) *Lime-soda ash treatment*, (b) *Ion exchange* by strong cation and anion exchanger resins; the deactivated resins require regeneration for their reuse, (c) *Reverse osmosis* consists of forcing water through a semipermeable membrane that allows the passage of water but not of other materials. It depends on the sorption of water on the surface of the membrane (porous cellulose acetate or polyamide) and the sorbed water is forced through the pores in the membrane under pressure.

Disease-causing pathogenic organisms require disinfection in cases where humans may later come into contact with the water. Chlorine and ozone are commonly used to disinfectant water other than drinking water for killing pathogens in water from sewage treatment plants, and to control viruses and bacteria in food processing. Chlorine dioxide is also effective water disinfectant, it does not produce trichloromethane as impurity in treated water, but it is explosive when exposed to light and does not chlorinate or oxidize ammonia or other nitrogen-containing compounds.

2.4.2.4 Immobilized Microorganisms for Water Treatment

Water originating from food or agricultural industrial processes can be contaminated with nitrate, that can be removed by denitrification methods generally employ special beads for immobilized biosystems, i.e., physical or physicochemical bonding of denitrifiers to the surface of insoluble carriers (sand, plastic, or ceramic particles). However, immobilized microorganisms, adsorbed by weak hydrogen bonds or by electrostatic interactions with the carrier, can be easily washed from the support into the treated water, resulting in microbial pollution [308]. Although an alternative method of immobilization by enzyme entrapment has been used, microorganism containment is a recent approach to wastewater treatment [309–312]. Cellular structures formed as a result of drying gels serve as matrices for the immobilization of denitrifying isolates. The dried beads have physical properties similar to those of porous, sponge-like matrices, with apparent air spaces within and around hydrocolloid-matrix walls. The beads revealed a matrix structure with variously sized pores that enabled gas release without matrix damage. The incorporation of starch granules within the matrix strengthened its structure. The dry matrices

sustained their biological activity over a prolonged period, meaning that the drying process did not damage the bacterial activity [313]. The starch incorporated into freeze-dried alginate beads can serve as a carbon source and filler. Freeze-dried beads containing high concentrations of starch were found to have better mechanical and denitrifying properties than beads containing low concentrations of filler [313].

2.4.2.5 Treated Water Uses

(A) **Agricultural uses.** Water is a basic component of all plants and is taken up from the soil via the root system, flowing up the plant by the osmotic gradient between the soil and the air. The water consumption of a crop can be broken down into three parts: (1) *Constituent water*, which is retained as a constituent part of the plant matter and used in combination with carbon dioxide to produce carbohydrates (photosynthesis), and to assist the uptake and transport of nutrients from the soil. (2) *Transpiration water*, which is taken up by the plant and lost as water vapor through the process of transpiration to provide cooling for aerial structures. (3) *Evaporation water*, which is lost by evaporation from the surface of the plant.

Water is available in soils from the evaporation and precipitation cycle that generates rain. The factors that affect agriculture are: soil type, rainfall distribution during the growing season, and climatic characteristics such as temperature and wind. The soil structure retains water in several different ways that will determine water availability to the plant: (1) *Drainage water* runs freely through the soil displacing air; it penetrates by gravity, is nonpermanent in the soil, and lost by percolation. (2) *Capillary water* makes up the majority of water in the soil and is the source of water for plants. This water is held in the soil by surface tension both on the surface of soil particles and in the capillary spaces between the particles. The capillary water capacity of a soil is lower for a sandy soil than for clay-containing soil. (3) *Interstitial water* is bound within the colloidal particles remaining from the gradual evaporation of both drainage and capillary water. The majority of this water is not available to the plant. (4) *Water vapor* within the soil pore spaces establishes equilibrium between its liquid state and the vapor level in the air, which is a negligible source of water to plants.

As water demands grow, treated wastewaters will increasingly be employed in agriculture. The direct application of wastewater to soil has yielded appreciable increases in soil productivity. Wastewater may provide the water that is essential to plant growth, in addition to the nutrients usually provided by fertilizers. All of the waste materials which are essential for soil fertility, may be absorbed by soil or degraded in soil. Soil is the natural habitat for a number of organisms (microorganisms, fungi, worms, etc.) that are active decomposers of wastes. The degradation of organic wastes in soil provides carbon dioxide for plant photosynthesis. Soils as natural filters for wastes have physical, chemical,

and biological characteristics that can enable wastewater detoxification, biodegradation, chemical decomposition, and physical and chemical fixation. A number of soil characteristics are important in determining their usability for land treatment of wastes, these include: physical form, water retainability, aeration, organic content, acid–base characteristics, and redox behavior.

- (B) **Industrial use.** Water is used in various industrial applications, as for instance as boiler feed water and cooling water. Cooling water may require minimal treatment, though removal of corrosive substances and scale-forming solutes may be necessary. Water used in food processing must be free of pathogens and toxic substances. Improper treatment of water for industrial use can cause problems, such as corrosion, scale formation, reduced heat transfer in heat exchangers, reduced water flow, and product contamination. These effects may cause reduced equipment performance or product deterioration. Obviously, the effective treatment of water at minimum cost for industrial use is an essential aspect of water treatment. Numerous factors must be taken into account in designing and operating an industrial water treatment facility: water requirement, quantity and quality of available water sources, sequential uses of water (water recycling), and discharge standards. The various specific processes employed to treat water for industrial use are: (a) *external treatment* by aeration, filtration, and clarification to remove suspended or dissolved solids, hardness, and dissolved gases from water that may cause problems, (b) *internal treatment* which modifies the properties of water for specific uses by: (i) reaction of dissolved oxygen with hydrazine or sulfite, (ii) addition of chelating agents to react with dissolved Ca^{2+} and prevent formation of calcium deposits, (iii) addition of precipitants for calcium removal, (iv) treatment with dispersants to inhibit scale, (v) addition of inhibitors to prevent corrosion, (vi) adjustment of pH, (vii) disinfection for food processing uses or to prevent bacterial growth in water.

2.4.3 Polymers in Irrigation

Irrigation is necessary to supply to the plant the water necessary for its needs that it otherwise would not receive by natural means. Although irrigation greatly increases the availability of food supplies and reduces their cost, failure to irrigate or excess irrigation is associated with adverse effects on crop production. Thus, irrigation is desirable or even required for economic crop production and for field crops grown in low water-holding capacity soils as well as for dry land farming where water is not available or costly. Irrigation has other significant effects on the environment resulting from the applied chemicals. Dissolved salts remain in the soil after irrigation and require drainage to remove excess salts from the plant root zone. Irrigation is usually provided by underground or surface reservoirs, as decrease in the irrigation table may lead to water stress that slows the growth of leaves and stems. Advantages resulting from proper irrigation include: (1) increased crop yield and

quality, (2) controlled time of planting and harvesting, (3) reduced damage from freezing and high air temperature, (4) increased efficiency of fertilizers and reduced cost of application, (5) a stabilized farm income. However, disadvantages of irrigation include increase in: (1) fertilizer requirements, seed costs, and more field operations, (2) weed growth that calls for use of herbicides, higher requirement of pesticides, and associated field operations, (3) water-borne diseases to animals and humans, (4) chemical contaminants in the root zone, (5) need for artificial subsurface drainage and leaching requirements, (6) detrimental effects on groundwater and downstream water quality, (7) conflicting demands on limited water resources.

2.4.3.1 Irrigation Water Quality

The chemical quality of water largely determines its suitability for irrigation and the most important characteristics of irrigation water are: (1) concentration of toxic elements, (2) concentration of soluble salts, i.e., water salinity, indicated by the electrical conductivity of the water (dS/m); the major ions causing water salinity are Na, Ca, and Mg cations. The rate of water flow is determined by its movement through the soil and is directly proportional to the soil pore space. Leaching is the only way to remove salts in the soil; this can be done by irrigation water. By frequent application of sufficient water excess salts can be dissolved and removed from the root zones by subsurface drainage.

Irrigation management needs to take into account: irrigation period, total irrigation water quantity and quality, soil salinity, effect of rainfall, and the efficiency of the irrigation system. The total seasonal irrigation requirement is the total amount of water that must be supplied over a growing season to plants. Irrigation is intended to provide optimum or maximum yield of crops; excess irrigation is undesirable because it decreases yields by reducing soil aeration and by leaching fertilizers away. Critical parameters include: (1) atmospheric conditions such as evaporative demand, radiation, temperature, wind, and humidity, (2) soil water retention, (3) the kind of crop and the rate of growth, (4) rainfall amount and intensity. During the early stages of growth the water needs are generally low, but they increase rapidly during the peak growing season to the fruiting stage, while during the later stages of maturity water use decreases as the crops ripen.

2.4.3.2 Irrigation Methods

Irrigation systems are categorized as flooding, soil surface spraying or sprinkling, and drip irrigation, which are all referred to in detail in the following:

- (A) **Surface irrigation.** Application of irrigation water by flooding the soil surface is the most widely used method in spite of the associated adverse effects caused to the land. Surface irrigation is the application of water to the soil by allowing the water to flow over the soil surface. Efficient surface irrigation requires

grading of the land surface to control the flow of water. It is the least efficient but predominantly used irrigation method in large irrigation areas, under conditions of: (1) flat soil land, (2) soils having high water-holding capacity and moderate infiltration rates, (3) large streams to cover the soil area quickly, (4) balance between soil and flow characteristics for optimum efficiency. The farm water supply is normally delivered either by conveyance ditches from surface storage or from irrigation wells. In surface irrigation systems, water is fed from a main channel into a series of ditches which are constructed to control the flow and aid in distributing the water over a field. The flow of water from the main channel into the gullies can be controlled by using PE siphon tubes. Gullies made from glass fiber-reinforced polyester have replaced concrete channels.

- (B) **Spray irrigation.** Water taken from the source (river, lake, well, or reservoir) is pumped through a distribution network system to feed sprayers or sprinklers which are spaced at regular intervals over the ground to be watered. Distribution irrigation systems are designed to distribute the water by means of a network of pipes using a variety of filters for the removal of solid matter. Pipes with slip joint connections have been commonly used for water distribution. Permanent systems are suitable for high-income crops because of the high labor cost in moving these systems. (a) *Spray irrigation systems* do not necessarily involve the transport of the water by pressure through a water-main for a small plot, since these can be readily watered by simpler means. An automatic pumping station is required for a system covering large areas of ground. Regular pipe-work systems are not designed for irrigation requirements subject to pressure surges due to the opening and closing of the valves. The overloading and reduction of pressure appears to accelerate the aging and deterioration of plastic pipes. These systems can be fully automated, fertilizer can be added to the water, nozzle holes are not to be liable to blockage by colloids. Drip or trickle irrigation does not cause leaching or compaction of the soil in contrast to other methods. (b) *Sprinkler irrigation systems* are automatic-timed systems and provide uniform application of water and can be used for lowering the temperature of plants by the cooling effect of evaporation. It is appropriate for circumstances where the soil infiltration rate exceeds the water application rate. It can provide a high efficiency of water application and its rate can be easily controlled. With this method, water is sprayed into the air and falls on the crop and soil, surface ditches are not necessary, prior land preparation is minimal, and pipes are easily transported and provide no obstruction to farm operations when irrigation is not needed. It is also well suited for sandy soils in which surface irrigation may be inefficient and expensive, or where erosion may be hazardous. Low amounts and rates of water may be applied, such as are required for seed germination, frost protection, delay of fruit budding, land application of wastewater, and cooling of crops in hot weather. This method can be used as a convenient means for the application of fertilizers, soil amendments, and pesticides to the soil or crop. It reduces energy and labor costs, and improves the effectiveness and timelines of the application. However, it is not suited for

Functionalized Polymeric Materials in Agriculture and
the Food Industry

Akelah, A.

2013, XIV, 367 p., Hardcover

ISBN: 978-1-4614-7060-1