AGRICULTURAL POLYMERS

D Jhurry

University of Mauritius

ABSTRACT

The need for improving the physical properties of soils to increase productivity in the agricultural sector was felt already in the 1950s. This led to the development of water-soluble polymeric soil conditioners. The latter had quite a short life-span and were rapidly withdrawn from the market mainly for economic reasons. Other polymers such as polyacrylamide which proved to be more efficient at lower application rates revived interest in the field. In the early 1980's, water-absorbing polymers or hydrogels were introduced for agricultural use. In this paper, both types of polymers and their benefits to soils are reviewed.

INTRODUCTION

Polymeric soil conditioners, were known since the 1950s (Hedrick and Mowry 1952). However, their wide commercial application failed even though the scientific basis for their use was quite well established. These polymers were developed to improve the physical properties of soil in view of:

- increasing their water-holding capacity
- increasing water use efficiency
- enhancing soil permeability and infiltration rates
- reducing irrigation frequency
- reducing compaction tendency
- stopping erosion and water run-off
- increasing plant performance (especially in structureless soils in areas subject to drought).

Among the products which initially appeared on the market, there was a copolymer consisting of vinyl acetate and maleic anhydride units (VAMA) known under the trade name Krilium®. It was withdrawn from the market for the following reasons:

- high cost exceeding the value of many crops
- complexity of application and poor distribution in the soil.

Most of the studies with polymers were performed in the laboratory or greenhouse without consideration for the economics at the production level in large-scale agriculture. When the polymer is mixed into the soil at rates of about 0.1% by mass, it translates into amounts of 1000 to 4000 kg ha^{-1}. Such rates are obviously not economical for most uses. The need for more arable land in view of increasing agricultural production has renewed interest in the development of novel soil conditioner materials with new methods and lower rates of application.

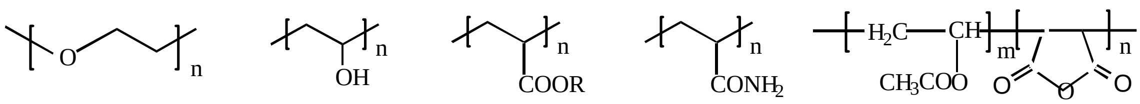
TYPES OF POLYMERS

Two distinct types of polymers have been studied and marketed for agricultural use. They are either soluble or insoluble in water.

Water-soluble Polymers

They were the first ones to be developed, primarily to aggregate and stabilise soils, combat erosion and improve percolation. Examples include both homopolymers and copolymers such as poly(ethylene glycol), poly(vinyl alcohol), polyacrylates, polyacrylamide, poly(vinyl acetate-alt-maleic anhydride). These possess linear chain structures as shown below. A list of some other soil conditioners is given in an excellent review on the subject in Azzam (1980).

Poly(ethylene glycol) Poly(vinyl alcohol) Polyacrylates Polyacrylamide Poly(vinyl acetate-alt-maleic anhydride)



All the polymers, except poly(ethylene glycol), are synthesised by free-radical polymerisation of the corresponding monomers. The latter are derived from the petroleum industry and are therefore easily accessible at low cost. One of the necessary characteristics of these polymers is a high molar mass. Polyacrylamide (PAM) is one of the most widely employed soil conditioner. More recently, polyelectrolytes such as acrylamide/acrylate copolymers have attracted much attention as they have been shown to be most effective in improving the physico-chemical properties of soils. Anionic character is imparted to polyacrylamide which is basically non ionic, either by copolymerisation with an unsaturated acid such as acrylic acid or by partial hydrolysis of amide groups. Polyacrylamide has also been used in combination with natural polysaccharides for soil-conditioning purposes. For example, Wallace et al. (1986a) showed that a mixture of a galactomannan, extracted from guar bean, and polyacrylamide resulted in an additive response when applied to certain soils.

We have developed at the University of Mauritius, linear vinyl polymers containing sucrose in the side chain. The synthesis of high molar mass hydrosoluble poly(O-methacryloylsucrose) has thus been achieved (Jhurry et al. 1992). The use of the latter as soil conditioner is currently under investigation.

Benefits of water-soluble polymeric soil conditioners

The success of PAM in modifying the calcareous nonfertile land near Dijon in France is a well-known example of its application. Tropical soils in intense high rainfall regions suffer from decrease in aggregate stability and increase in bulk density. Consequently, water intake and storage are reduced while surface drainage increases. PAM has proved to be effective against soil erosion. Indeed, treatment of the soil of Lambang (Indonesia) with PAM has made it possible to reduce soil losses under rainfall from 17 000 to 4000 kg ha^{-1}. The permeable layer of soil produced by the conditioner stabilises the soil, thus preventing runoff (for example, when 300 kg ha^{-1} PAM was applied to soil, the water runoff decreased by 177%). Another important point is that the penetrability of water in a PAM treated soil increases by a factor of 2.5 while its mean diffusivity increases four fold.

The effect of the polymeric soil conditioners on plant growth and crop yield has also been extensively studied. The rates of germination and emergence of a number of plants such as tomato, lettuce or maize increased markedly in the presence of the conditioner (Wallace and Wallace 1986a). Other studies (Batyuk et al. 1973) have shown that the yield of (sugar beets) is increased while the requirements for irrigation decreased by the use of the conditioners. A number of reasons have been put forward to explain these observations: better soil aeration, thereby enhancing microbial activity ; delaying dissolution of fertilisers ; increasing sorption capacity or favouring the uptake of some nutrient elements by the plants.

Wallace and Wallace (1986b) showed that very low concentrations of a mixture of PAM and a polysaccharide (below 0.001% or 22 kg ha^{-1}) have a favourable effect on the physical properties of soils, particularly regarding percolation and infiltration rates as well as the sizes of soil particles. Poly(vinyl acetate-maleic anhydride) formerly used, was also tested for comparison. It is interesting to note that improvements were recorded with VAMA only when the concentrations of polymer exceeded 0.01%, that is an order of magnitude higher. The possible application of very low rates of soil conditioners makes their use economically feasible. Some researchers (Wallace and Wallace 1986b) have developed soil tests for predicting the effective quantities of soil conditioners required to achieve desirable physical properties of soils. These tests relate to application of polymers in irrigation water and are as follows (1) determining rates of polymers to achieve flocculation of the soil in test tubes, (2) filtering and air-drying the aggregates to evaluate water stability, (3) testing a range of concentrations of polymers to determine the rate that preserves existing soil aggregates (4) treating small samples of soils with polymers for water penetration tests, (5) wet-sieving control soils and soils treated with polymers while in suspension.

More industrial applications are being developed for the polymeric soil conditioners. For instance, wastes such as fly ash can be stabilised. Farm roads may also be sprayed with solutions of polymers to control dust.

Gel-forming polymers

This second class of polymers referred to as gel-forming polymers or insoluble water-absorbing polymers were first introduced for agricultural use in the early 1980's. These polymers do not possess linear chain structures as described previously but the chains are rather cross-linked to form a three-dimensional network. Cross-linking occurs when polymerisation is carried out in the presence of a small amount of a divinyl compound. Depending on synthetic conditions, type and density of covalent bonds that form cross-links, these polymers can absorb up to 1000 times their weight in pure water and form gels. Three main types of hydrogels (water absorbing) have so far been developed as agricultural polymers: (1) starch-graft copolymers obtained by graft polymerisation of polyacrylonitrile onto starch followed by saponification of the acrylonitrile units (2) cross-linked polyacrylates (3) cross-linked polyacrylamides and cross-linked acrylamide-acrylate copolymers containing a major percentage of acrylamide units. Most of the hydrogels marketed for agriculture come from the latter group as they are claimed to remain active for a much longer time.

Benefits of hydrogels

Researchers (Flannery and Busscher 1982; Johnson 1984a) have reported that the use of hydrogels increases the amount of available moisture in the root zone, thus implying longer intervals between irrigations. It must be pointed out that the polymers do not reduce the amount of water used by plants. The water-holding capacity depends on the texture of the soil, the type of hydrogel and particle size (powder or granules), the salinity of the soil solution and the presence of ions. Cross-linked polyacrylamides hold up to 400 times their weight in water and release 95% of the water retained within the granule to growing plants. In general, a high degree of cross-linkage results in the material having a relatively low water-retention capacity. However, the water-holding capacity drops significantly at sites where the source of irrigation water contains high levels of dissolved salts (e.g effluent water) or in the presence of fertilizer salts (Wang and Gregg 1989). The amount of water retained is also adversely affected by chemicals or ions (Mg^{2+}, Ca^{2+}, Fe^{2+}) present in the water (Johnson

1984b). James and Richards (1986) suggested that these divalent cations develop strong interactions with the polymer gels and are able to displace water molecules trapped within the polymer. Even though monovalent cations (Na+) can also replace water molecules, the effect is not as pronounced as with the divalent counterparts as the process is fully reversible by repeated soaking with deionised water.

Moreover, the use of hydrogels leads to increased water use efficiency since water that would have otherwise leached beyond the root zone is captured. During hot days, the hair root system of a plant pulls out and depletes most of the water from the area close to the root system, thus causing the plant to go into stress. While increasing the amount of available moisture, hydrogels help reduce water stress of plants resulting in increased growth and plant performance (El-Hady et al. 1981; Pill and Jacono 1984; Baker 1991). The performance of the gel on plant growth depends on the method of application as well. It was shown that spraying the hydrogels as dry granules or mixing them with the entire root zone is not effective (Flannery and Busscher 1982). Better results seem to be obtained when the hydrogels are layered, preferably a few inches below soil surface. However, generalisations should be avoided when interpreting results as a number of factors such as type of hydrogel, particle size, rate of application and type of plant has to be taken into consideration.

Hydrogels are also claimed to reduce fertilizer (NPK) leaching. This seems to occur through interaction of the fertilizer with the polymer. The loading of NPK fertilisers directly into cross-linked polyacrylamide gels is now receiving more and more attention at research level. Cross-linked polyacrylamide is also being considered as a potential carrier for insecticides, fungicides and herbicides.

CONCLUSION

The beneficial effects of both water-soluble soil conditioners and hydrogels on soil physical properties is a well-established fact. Numerous publications describe the increase in yield of various plants as a result of better soil conditions. A lot of research effort has also been geared towards lowering the rate of application of polymer. However, in most cases these studies have not been extended to large scale agriculture and application rates for most economical yields are not as yet defined. This implies still more research work on a crop by crop basis for only area.

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COMMENTS

Q. What is the stability of polymers used for water conservation?

A. They have a life time of about seven years.

Q. How much should be applied and to what depth?

A. Recommendations have to be made on a crop to crop basis.

Q. Will polymers derived from sugar molecules have a short life time?

A. The degradability will depend on linkages type.