Degradation of Water-absorbing Polymers Used as Soil Ameliorants

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ABSTRACT. The decomposition of gel-forming polymers used to enhance water retention in sandy soils has been studied. Starch and urea-based polymers are liable to microbial degradation in a short time, whereas polyvinylalcohol and cross-linked polyacrylamides persist in a chemically unaltered state for longer periods.

These observations have important practical implications because when decomposition occurs the gel-forming character is lost together with the ability to store moisture in drought-prone soils. Careful attention should be paid to environmental conditions in the selection of suitable polymers for specific purposes.

The introduction of synthetic, highly-absorbent polymers that serve as slow-release water reservoirs is a significant new development to aid plant growth under conditions of moisture stress. These additives to soil and compost are capable of absorbing several hundred times their own weight of water, and are now widely used in arid climates, in glasshouse production, and outdoors in temperate regions where short-term water stress may occur. The moisture is released more slowly than the rate of loss by normal evapotranspiration from soil-plant surfaces, and this minimises drought loss of planting stock, optimises plant recovery of water, and dramatically improves efficiencies in fresh weight production per unit of water supplied (EI-Hady *et al.* 1981).

Many factors influence the water-storage capability of polymers and their effectiveness. Important variables include water-binding tensions within the polymer matrix, soluble salts in the irrigation water, and temperature relations. However, there is only sparse information on one important feature of these substances, namely their persistence in soil. This is important in any cost-benefit assessment because polymers are commonly used not only to minimise drought losses at ger-

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mination and seedling establishment, but as long term aids to water supply – sometimes over several years.

Under conditions of moderate to high temperatures and in the presence of water, most soil materials – organic or inorganic – are biodegradable. In the case of natural polymeric substances in the soil, their chemical structure is drastically altered by the actions of invertebrates and micro-organisms, the resulting products being simpler chemicals that do not display the properties of the original compounds. Applying the same principles to synthetic polymers, which have at least the potential for decomposition, the water absorption powers could gradually be lost as the polymers degrade through biological action.

The decomposition of soil organic compounds is achieved by a great diversity of small soil animals classed as detritivores acting in unison with soil micro-organisms, namely heterotrophic bacteria, fungi and actinomycetes. Together they utilise organic debris as a source of energy and nutrients. The energy-yielding process of respiration involves free exchanges of oxygen (O_2) and carbon dioxide (CO_2). Measurements of CO_2 evolution under controlled conditions can be used to determine whether specific substances are biodegradable, as well as the rapidity and degree to which they are mineralisable. Monitoring of microbial metabolism *via* respiration is an accepted procedure for determining carbon mineralisation and has been applied previously to a range of synthetic organic chemicals.

This paper describes the results of comparative decomposition measurements on gel-forming polymers widely used in amenity horticulture, forestry, and landscape restoration. The test materials were chosen one from each of four major groups of polymer in current use. These are (a) hydrolysed starch-polyacrylonitrile graft co-polymers, (b) urea-formaldehyde resin foams, (c) vinyl alcohol-acrylic acid co-polymers, and (d) cross-linked acrylamide co-polymers.

Members of these four classes of polymer have well recognised differences in water absorption and release properties and sensitivity to other factors but no evaluation has been conducted hitherto on their persistence under simulated operating conditions.

Material and Methods

Experimental work was conducted in a controlled environment growth room with 24 hr illumination and a constant temperature of 30°C. Five replicated samples of each polymer were placed in 50 ml polypropylene beakers in sealed, air-tight bell-jars under which was also placed a 30 ml sample of 2 M sodium hydroxide as a carbon dioxide diffusion trap. Control treatments were established without polymer to correct for carbon dioxide absorption from the atmosphere.

Polymer samples were expanded in 20 ml of a settled deionised water extract of neutral humus and litter taken from beneath a fertile mixed deciduous woodland. Serial dilution plate counts using nutrient agar for bacteria and peptone-dextrose agar for fungi were used to confirm a diverse and abundant microbial flora in the organic matter extract. In view of the chemical composition of the polymers, the C : N ratio of the potential substrates was modified to < 30 : 1 by adding ammonium nitrate (8 mg/l) to the litter extract. Di-potassium hydrogen phosphate was also added at 5 mg/l.

Carbon dioxide evolution was monitored by pipetting 5 ml aliquots from each sodium hydroxide pool at set intervals, followed by titration against 2 M hydrochloric acid using phenolphthalein indicator. Barium chloride (3 M) was used to precipitate the absorbed carbon dioxide as barium carbonate.

In view of the very different elemental composition of the three polymers, carbon dioxide evolution alone provides only a guide to relative rates of decomposition. Consequently, weight losses over time were also recorded by (a) calculation based on the total percentage carbon in the original polymers, and (b) from time-interval weighing, and final weighing after oven-drying at 60°C.

Results and Discussion

The results of the polymer incubation trials are shown in Table 1, summarising cumulative carbon dioxide evolution (mg), and Table 2 showing cumulative weight loss (%), both over a period of six weeks. It is evident from the data that the representatives of the four different chemical families of soil conditioning polymers showed great variation in their behaviour and persistence.

Following an initial equilibration and lag-phase of the order of 7 days, both the starch-polyacrylonitrile co-polymer and the urea-formaldehyde resin foam

Delementer	Time in weeks							
r olymer type	1	2	3	4	5	6		
Starch-								
polyacrylonitrile	5.6	19.6	39.8	47.4	55.0	58.0		
Urea-formaldehyde Vinyl alcohol	3.0	6.1	8.6	12.3	16.1	21.0		
acrylic acid Polyacrylamide	0 0	2.4 0	4.1 0	4.2 1.1	6.0 1.1	8.3 2.1		

Table 1. Cumulative evolution of CO₂ (mg) from standard weights (200 mg) of gel-forming polymers under incubation.

Least significant difference at p < 0.05 = 6.9.

D. I	Time in weeks							
Polymer type	1	2	3	4	5	6		
Starch-								
polyacrylonitrile	1.9	6.7	13.6	16.1	18.7	19.7		
Urea-formaldehyde	1.4	2.7	3.9	5.6	7.3	9.5		
Vinyl alcohol								
acrylic acid	0	1.4	2.4	2.8	3.5	4.9		
Polyacrylamide	0	0	0	1.5	1.5	2.8		

Table 2.	Cumulative	weight	loss	(%)	due	to	polymer	decomposition	by
	microbial activity.								

Least significant difference at p < 0.05 = 3.9.

showed rapid decomposition, producing total weight losses after six weeks of 19.7% and 9.5%, respectively. Both these polymers are chemically rather similar to naturally-occurring substances in soil-plant systems. Starch - the major storage polysaccharide in plant materials – is readily degraded by phosphorolytic cleavage through starch phosphorylase and by hydrolytic cleavage via the enzymes α - and β -amylase. Urea is the natural substrate of the enzyme urease, and is readily hydrolysed through the activities of ureolytic micro-organisms. This pattern of deterioration with time was less evident for the vinyl alcohol-acrylic acid copolymer, and virtually undetectable in the case of the cross-linked polyacrylamide. These complex, high molecular weight polymers are evidently much more resistant to microbial degradation, and liable to provide more effective water-storage support for plant growth in the long term. This was further evidenced by water re-absorption trials on the polymer residues from these incubation trials which, in the case of the starch and urea-based polymers, indicated an almost total loss of the hydrophilic, gel-forming character as a result of chemical decomposition during the incubation phase. Surprisingly, the decline in water storage capacity also applied to the vinyl alcohol-acrylic acid co-polymer, even in the absence of measurable decomposition.

Conclusion

Though there is no uniformity of opinion about the merits and disadvantages of different gel-forming polymers, the results of this incubation trial confirm the biodegradable nature of starch-based polymers (Alston 1982), and urea-formaldehyde resin polymers. They also support the developing view that cross-linked polyacrylamides are not subject to decomposition in the short to medium term (Grula and Huang 1982). These observations have important practical implications in the use of gel-forming polymers as soil conditioners to improve moisture retention and supply to growing plants under field and glasshouse conditions.

The diversity of water-storing polymers developed to aid germination, seedling establishment and long-term growth under conditions of moisture stress has led to difficulties in product selection. Many factors should influence the decisions as to which polymer to use, not least the water-storage capacity and binding tensions at equilibrium, the rate of water loss and the nature and concentration of salts in local irrigation waters. The durability of the soil conditioner is an equally important consideration, especially where the temperature, moisture, and microbial conditions require polymers that resist biodeterioration.

In arid climates, where synthetic polymers provide vital support for the growth of horticultural and agricultural crops, amenity trees, and grassland – both as direct additives and as compost supplements – considerable care should be taken to ensure that the chosen polymer is suited to the prevailing environmental conditions and objectives.

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التحلل الاحيائي للبوليمرات الممتصة للماء المستعملة كمحسن للتربه

لقد درس التفكك الاحيائي للبوليمرات المكونة للجل المستعملة لزيادة الاحتفاط بالماء واسترجاعه في التربة الرملية. فان القواعد البوليمرية للنشا والبولينا تكون عرضة للتحلل الميكروبي في وقت قصير على أن الكحول البوليفينيلي والبولى أكريلاميدات المتصالبة تقاوم في حالة غير متغيرة كيميائيا لمدة طويلة.

وكان لهذه الملاحظات أهمية كبيرة في التطبيق لانه عندما يبدأ التحلل فان حالة تكوين الجل تختفى مع القدرة على تخزين الرطوبة في أنواع التربة المهيأة للجفاف. ولابد من عناية مركزة على ظروف البيئة لاختيار البوليمر المناسب لأغراض محددة.