Water and nutrient retention by Aquasoil and Stockosorb polymers

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Water retention and hydration rate of Aquasoil and Stockosorb polymers, the effects of these polymers on the water, ammonium and nitrate retention of a pine bark growth medium and the response of the polymers to fertilizer solutions were investigated. Aquasoil retained 129 g of distilled water g"[1] of polymer, whereas Stockosorb retained 216 g"[1] of polymer. Both polymers reached their maximum capacity in about one hour. The polymers when combined with 1 or 2 g 500 g"[1] of pine bark, improved the water retention capacity of the growth medium. However, longer time was required in the growth medium for the polymers to reach maximum capacity than in the distilled water. All polymer-amended pine bark media retained more ammonium, compared to non-amended media. The 2 g polymer treatment retained greater amounts of $N0_3$ than the lower rates. Retention of water by the Aquasoil® and Stockosorb® polymers was reduced to 88% and 86% of capacity compared to distilled water, whereas fertilizer solution reduced water retention to 53% and 42% of capacity. Soaking in distilled or tap water improved water retention of the polymers over fertilizer solutions.

Introduction

Gel-forming polymers are small dry crystals that absorb water similar to sponges. Contact between the polymer granule and water results in absorption until equilibrium is reached (Woodhouse & Johnson, 1991). When polymers are incorporated into a soil or soilless medium, it is presumed that they retain large quantities of water and nutrients. These stored water and nutrients are released as required by the plant. Thus, plant growth could be improved, and/or water supplies conserved. Johnson (1984b) reported a 171% to 402% increase in the water retention capacity when polymers were incorporated in coarse sand. Addition of a polymer to peat: perlite mixture decreased water stress and increased the time to wilt in zinnias (Gehring & Lewis, 1980). Results from literature also showed that increased water retention capacity attributed to polymer addition significantly reduced irrigation frequency (Gehring & Lewis, 1980; Flannery & Busscher, 1982) and the total amount of irrigation water required (Taylor & Halfacre, 1986).

However, other reports have shown little or no benefit from polymers added at the recommended rate (Henderson & Hensley, 1986; Lamont & O'Connell, 1987). Fry and Butler (1989) concluded that the alleviation of water stress in tall fescue grown in fine-textured sand would require polymer additions of more than 80 times the recommended rate. In many studies conducted (Johnson, 1984a; Taylor & Halfacre, 1986; Lamont & O'Connell, 1987), the reduction or absence of the beneficial effect of adding a polymer may have been due to limited polymer hydration because of dissolved salts in the irrigation water or fertilizer.

Polymers with various chemistries are currently available on the market. Polymers used in this study are highly cross-linked polyacrylamides. Stockosorb® is a potassium based nutrient-free co-polymer, whereas Aquasoil® is a fused blend of nutrients and potassium-based co-polymer, consisting of 8.96% N, 5.64% P and 5.05% K. Manufacturers claim that the super-absorbent polymer contained in Aquasoil® and Stockosorb® polymers can retain large quantities of water and nutrients.

The objectives of the study were to determine water retention and hydration rate of Aquasoil® and Stockosorb® polymers, the effect of these polymers on water, ammonium and nitrate retention of a pine bark medium and the response of the polymers to a fertilizer solution.

Material and methods

To determine water retention of the polymers, 1 g of each dry polymer was placed in a beaker and then filled with 1 1 of distilled water. Polymers were allowed to stand in the water for 2 h. Excess water was drained through a 106 *µm* sieve for five minutes, and the mass of hydrated materials was recorded. Each treatment was replicated nine times in a completely randomized design.

To determine the rate of water uptake by Aquasoil® and Stockosorb® polymers, 1 g of each polymer was placed in a beaker. Each beaker was filled with 1 1 of distilled water. Polymers remained in water for 5, 10, 20, 30, 60, 120, or 240 minutes, drained for five minutes through a 106 µm sieve, and the mass of hydrated materials was recorded. Each treatment was replicated four times in a completely randomized design.

To determine the effect of polymers on water retention of a medium, pots were filled with 500 g of pine bark. Aquasoil® and Stockosorb® polymers were incorporated into the medium at levels of 0, 1, or 2 g pot^{-1} . The pots were placed on a bench, irrigated twice the first day, each time with 500 ml of water and allowed to drain for 30 minutes before mass of the pots was recorded. For each of the next 11 days, each pot received 500 ml of water and was weighed after having drained for 30 minutes. Each treatment was replicated three times in a randomized complete block design.

To determine nutrient retention by polymers, 2 g of ammonium nitrate was applied to plastic pots filled with 500 g of bark amended with 0, 1, or 2 kg $m^{\sim 3}$ of Aquasoil® and Stockosorb® polymers. One litre of distilled water was then applied to the pots and the leached solution collected for ammonium and nitrate analysis. Each treatment was replicated three times in a randomized complete block design.

To determine the effect of different sources of water on water retention of polymers, 1 g of each polymer was placed in individual beakers. The beakers were filled with 1 1 of distilled or tap water, or with a solution containing 1 g of water soluble fertilizer commercially known as 'Feed All'. A kilogram of 'Feed All' consisits of 160 g N, 50 g P, 220 g K, 11 g Ca, 3 g Mg, 335 mg B, 356 mg Fe, 100 mg Zn, 125 mg Mn, 12.5 mg Mo and 12.5 mg Cu. Polymers were immersed in solutions for 4 h, drained for 5 min, and their mass recorded. Each treatment was replicated four times.

To determine the recovery of water uptake by the two polymers after exposure to fertilizers, 1 g of each polymer was sequentially soaked in 11 of tap water for 24 h, distilled water for 24 h, a solution containing a water soluble fertilizer ('Feed All') for 24 h and again in tap water for 24 h, then finally in distilled water for 24 h. After each soak, excess solution was drained for 5 min and the mass of the polymers was recorded. Each treatment was replicated four times.

The results of all the experiments were subjected to analysis of variance using the General Linear Model (GLM) procedure of the Statistical Analysis System (S AS) and Tukey's t-test (SAS Institute, 1999) was used to test for differences between treatment means.

Results and discussion

Stockosorb® retained 216 times its dry mass of distilled water, while Aquasoil® retained about 129 times its mass (Table 1). In both polymers, this finding did not support claims by the manufacturers that the polymers can retain up to 300 times their mass in water. The most possible reason for the lower retention of water by Aquasoil®, as compared to that of Stockosorb®, may be due to the nutrients fused into the structure of the Aquasoil polymer. Increased water retention by the Stockosorb® polymer, where no nutrients are fused, indicates that more sites become available for water retention. Reduced number of absorption sites would allow the water to move more readily through the Aquasoil® treated medium and more water is therefore leached.

Polymers are of different types with different capacities. According to Johnson (1984a), starch co-polymers have extremely high theoretical retention capabilities. They have many polar hydroxyl groups that make it easier for the polar molecules to be adsorbed to the hydrogel. This results in fast water uptake and expansion of the material (Wang & Gregg, 1990). In deionised water, starch co-polymers retained up to 687 times their mass, while cross-linked polyacrylamides retained from 44 to 515 times their mass (Woodhouse & Johnson, 1991). The amount of water a polymer can retain depends on the density of the cross-linkage. The more the cross-links, the lower the amount of water the polymer retains (Allcock & Lampe, 1990; Wang & Gregg, 1990). The relatively low water retention of Aquasoil® and Stockosorb® polymers in this experiment may, therefore, be attributed to their higher degree of cross-linkage.

Table 1 Water retention by Aquasoil® and Stockosorb® polymers soaked in distilled water over a period of 2 hours

Type of polymer	Water absorbed (g) g"[1] polymer
Stockosorb®	216.8 a
Aquasoil®	129.7 b

Values followed by the same letter are not significantly different at P = 0.05

Rate of hydration

Polymers showed rapid initial hydration followed by a progressive decrease in the rate of absorption towards the point of equilibrium (Table 2). Both polymers had a similar pattern in the rate of water absorption. Absorption of water was rapid such that more than 84% of full absorption was achieved within five minutes. Aquasoil® started to reach its maximum capacity in 30 min. After 30 min, there was a gradual but not significant increase in the amount of water absorbed. Although there was no significant difference after 10 min, Stockosorb® also continued to absorb water for 60 min, until it reached its peak retention capacity. Both polymers attained full capacity in about one hour. According to Wang and Gregg (1990), complete hydration took up to 12 h in some polyacrylamide polymers.

Substantial losses of irrigation water occur by extensive percolation in coarse soils. The speed and efficiency of any storage facility is therefore crucial. If a slow hydrating polymer is used, a relatively longer period of irrigation has to be provided for the polymer to expand fully. This is because much water can be lost through run-off, percolation or leaching during the expansion phase of the polymer. In such cases, using Aquasoil® and Stockosorb® polymers, having a fast absorption rate, with 94% of their capacity reached in 20 min (Table 2), would be ideal.

Effect of polymers on medium water retention

Polymer amendment increased water retention of a pine bark medium, compared to the medium with no polymer (Table 3). In all cases, water retention of the medium increased with increasing polymer level, and Stockosorb® was always superior to Aquasoil®. The mass of the pot continued to increase with increasing number of irrigations (Table 3), with significant differences among levels and types of polymers. The 2 g

Table 2 Effect of time of contact between polymer and water on water absorption by Aquasoil® and Stockosorb® polymers

	Mass of water absorbed (g) g of dry polymer	
Time (Min)	Aquasoil®	Stockosorb®
5	114.1 b	199.5 b
10	125.0ab	212.6ab
20	127.3ab	213.0ab
30	133.5a	214.8ab
60	134.8a	225.8a
90	135.8a	220.3a
120	134.9a	224.6a
240	135.2a	225.5a

Values followed by the same letter in a column are not significantly different at P = 0.05.

Table 3 Effect of Aquasoil® and Stockosorb® polymers on water absorption by a pine bark medium. Each pot contained 500 g of the medium at the beginning

Days	Control	1 g Aquasoil®	2 g Aquasoil®	1 g Stockosorb®	2 g Stockosorb®
1	948.3 C (c)	977.0 E (c)	1064.6 E (b)	1056.2 E (b)	1246.3 E (a)
2	1027.3 B (d)	1075.4 D (cd)	1168.9 D (b)	1131.4 D (bc)	1332.4 D (a)
3	1044.3 AB (d)	1112.5 DC (c)	1207.6 CD (b)	1182.4 DC (b)	1379.2 DC (b)
4	1058.4 AB (d)	1141.3 BC (c)	1234.3 BCD (b)	1222.2 BC (b)	1426.2 BC (a)
5	1072.3 AB (d)	1164.8ABC (c)	1262.7 ABC (b)	1253.3 AB (b)	1442.9 AB (a)
6	1078.1 AB (d)	1183.4 AB (c)	1274.2 AB (b)	1260.2 AB (b)	1448.7 AB (a)
7	1079.5 AB (d)	1196.1 AB (c)	1299.3 AB (b)	1277.8 AB (b)	1479.1 AB (a)
8	1081.4 AB (d)	1201.0 AB (c)	1302.4 A (b)	1278.1 AB (b)	1484.8 A (a)
9	1093.7 A (d)	1204.5 A (c)	1303.6 A (b)	1282.4 AB (b)	1488.3 A (a)
10	1099.4 A (d)	1209.3 A (c)	1307.3 A (b)	1283.6 AB (b)	1492.0 A (a)
11	1100.1 A (d)	1211.3 A (c)	1306.2 A (b)	1288.6 A(b)	1491.0 A (a)
12	1099.7 A (d)	1210.3 A (c)	1308.6 A (b)	1287.0 A (b)	1493.0 A (a)

Values followed by the same letter in a column (upper case letters) and row (lower case letters) are not significantly different at P = 0.05

Aquasoil® treatment and the 1 g Stockosorb® treatment had similar effects during the entire irrigation period, with the 2 g Aquasoil® treatment performing slightly better. Pots without the polymer started to reach maximum water retention capacity earlier. All the polymer amended pots in general, and those amended with the higher polymer rates in particular, continued to absorb relatively more water for a longer period of time.

The water absorption pattern (Table 3) also shows that the medium did not reach its maximum hydration until several irrigations, especially in the presence of polymers. Although one hour was enough for the polymer to reach full hydration in distilled water (Table 2), they took much longer to reach full expansion in the growth medium (Table 3). This suggests that polymers may require the presence of free water for quick expansion and are unable to extract water effectively from unsaturated medium. For a polymer to be effective, the potential of the water has to be near field capacity, because polymers are unable to extract water effectively from their surroundings. Polymers simply immobilize water that comes in contact with them (Baxter & Walters, 1986; Bowmans, Evans & Paul, 1990).

Coarse textured soils have low water retention capacities that may lead to substantial losses of water by excessive percolation. The productivity of these soils is thus reduced and more water is wasted. Aquasoil® and Stockosorb polymers® can be used for amending such soils to improve their capacity to hold water.

Nutrient retention

Results of ammonium and nitrate retention by Aquasoil® and Stockosorb® polymers are given in Table 4. In the medium without polymer, 40% of the ammonium applied was retained. Polymer amendment of the medium at all rates resulted in a higher retention of ammonium. There was no significant difference among all types and rates of polymer treatment in their ammonium retention. However, the general trend was that with increasing polymer rate, the amount of ammonium retained increased and Stockosorb® consistently but not significantly, retained more ammonium than the Aquasoil® polymer.

Compared to ammonium, more nitrate was lost from all the polymer-treated and non-treated growth media (Table 4). Fifty five per cent or more of the nitrate was leached from the pots for all the treatments. In comparison to the control, the 2 g treatment of both polymers retained significantly higher rates of nitrate. The 1 g treatment of both polymers consistently, but not significantly, retained more nitrate than the non-amended medium. There was no significant difference between the two types of polymer treatments in their nitrate retention. For both polymers the 2 g treatment retained significantly higher nitrate than the 1 g treatment.

According to Magalhaes *et al.* (1987), polymer addition had a great effect in reducing ammonium leachates but not in nitrate, except in dried soil. Polymer amendment of silica sand at the rate of 2 to 4 kg m^{-3} retained significantly higher rates of ammonium. Polymer treatments did not bring about a significant difference in the nitrate retention of the medium (Henderson & Hensley, 1985). Different responses to the two formulations of nitrogen could be attributed to the ionic differences, and resulting differences in solubility. The positively charged ions are absorbed readily and are retained by negatively charged surface of clay or organic particles. This

Table 4 Percentage of ammonium and nitrate retention by pine bark amended with Aquasoil® and Stockosorb® polymers leached with distilled water

Type and rate of polymer	Ammonium%	Nitrate%
2 g Stockosorb®	82.0 a	44.1 a
2 g Aquasoil®	76.3 a	36.6 a
1 g Stockosorb®	67.9 a	25.2 b
1 g Aquasoil®	64.6 a	20.9 b
Control	40.5 b	17.3 b

Values followed by the same letter in a column are not significantly different at P = 0.05

ionic attraction reduces the leaching of the ammonium ion (NH_4^+). In contrast, nitrate ion ($N0_3$~) is very mobile and leaches readily from the soil (Tisdale & Nelson, 1975).

The results of this experiment have clearly demonstrated the potential of Aquasoil® and Stockosorb® polymers to alleviate problems related to ammonium and to some extent nitrate loss from the growth media. Increased plant nutrient level and reduced loss of nutrients in polymer-amended media were also reported from other findings (Abraham & Pillai, 1995; Mikkelsen, 1995; Taylor & Halfacre, 1986).

Effect of source of water and fertilizer solution

The maximum water retention by each polymer after soaking in all types of water varied significantly (Table 5). Stockosorb® had higher water holding capacity than Aquasoil® in all cases. Both polymers retained less water when hydrated in tap water or in water containing fertilizer. In tap water, total absorption was reduced to about 88% and 86% of that in distilled water for Aquasoil® and Stockosorb® polymers, respectively. Fertilizer solution significantly reduced absorption by both polymers. However, Stockosorb® was affected more, reaching only 42% of its maximum capacity in distilled water, whereas Aquasoil® reached about 53% of its maximum capacity. The apparently lower rate of reduction in the water absorbing capacity of the Aquasoil®, as compared to that of the Stockosorb®, may be because of the already reduced capacity of Aquasoil® due to the nutrients fused in its structure. The total amount of water absorbed at the end of the experiment was, however, higher for Stockosorb® than for the Aquasoil®. This may be explained by the fact that many of the sites in the Aquasoil® are occupied by the slow release nutrients fused into it, reducing the available space for water absorption.

Soluble salts considerably affected absorption by Aquasoil® and Stockosorb® polymers, which is consistent with previous reports (Johnson, 1984a: Lamont & O'Connell, 1987). The degree of reduction in water holding capacity of a particular polymer depends on the structure and chemical composition of the product and the concentration and variety of ions in the soil solution to which the polymer is being exposed (Wang, 1989). Earlier work has shown that fertilizer solutions reduced polymer water absorption ability by as much as 75 to 90% (Bowmans *et al.*, 1990). In the present study, the reduction in absorption rate due to fertilizer solutions was 47 to 58% (Table 5). This may indicate better buffering capacity of Aquasoil® and Stockosorb® polymers to fertilizer solutions. Another possible reason for the relatively

Table 5 Effect of water source and fertilizer solutions on water retention of Aquasoil® and Stockosorb® polymers

	Water absorbed (g) g^{-1} of dry polymer	
Water source	Aquasoil®	Stockosorb®
Distilled water	132.3 a	224.2 a
Tap water	116.1 b	192.8 b
Fertilizer solution	69.5 c	94.1 c

Values followed by the same letter in a column are not significantly different at P = 0.05

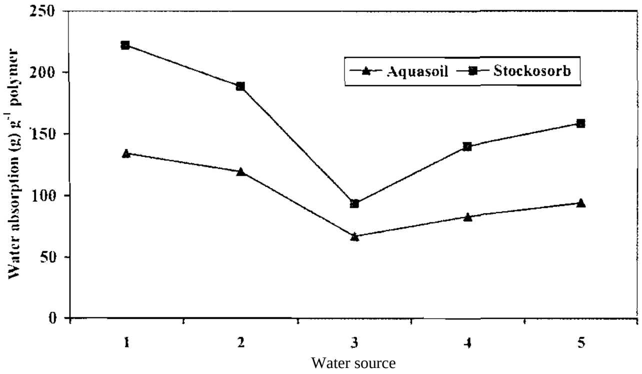

Figure 1 Recovery of Aquasoil® and Stockosorb® polymers after exposure to fertilizer solution. Legend: 1 Distilled water, 2 Tap water, 3 Fertilizer solution, 4 Tap water, 5 Distilled water.

better performance of these two polymers, compared to the 75 to 90% reduction in absorption capacity or complete destruction of other polymers, may be because the fertilizer solution used in this experiment contained a combination of different nutrients. Combining fertilizers have reduced the impact of salt solution on some polymers (Foster & Keever, 1990). However, the general effect of cationic disruption of polymers suggests that cations actively remove and replace water at sites upon and within the co-polymer (James & Richards, 1986).

Recovery of polymers

The reduced water-holding capacities of Aquasoil® and Stockosorb® polymers, as a result of soaking in tap water and fertilizer solution, were partially recovered after a soak in distilled water (Figure 1). Soaking in distilled water after being exposed to fertilizer solution restored water absorption capacity of Aquasoil® to 70% of its original capacity in distilled water and 79% of its original capacity in tap water. Stockosorb® showed slightly better recovery than Aquasoil®. The reduced absorption due to fertilizer solution was restored to 71.4% and 84% of that in distilled and tap water, respectively. Soaking the polymers in tap water after being exposed to fertilizer solution also increased the water retention capacity of Aquasoil® by 24% and that of Stockosorb® by 50%, compared to their capacity in the fertilizer solution. These results prove that the reduced water absorption of Aquasoil® and Stockosorb® polymers, brought about by fertilizer ions is partially reversible.

Bowmans *et al.* (1990) showed that repeated soaking of polymers in deionised water fully reversed the hydrophobic reaction with monovalent ions, whereas the damaging effect of divalent ions on polymer water retention was only partially reversed. Wang and Gregg (1990) reported a complete destruction of the integrity of several polymers by ferrous sulphate other than those made of polyacrylamides. Water retention capacity in all of the polymers, other than the polyacrylamides, was therefore irreversibly destroyed.

Conclusions

Aquasoil® and Stockosorb® polymers can absorb large quantities of water. They have a fast rate of hydration, which is a very important characteristic in the selection of polymers for field use. Application of the polymers would likely increase water and nutrient retention of growth media. The polymers took longer time in a potting medium than in pure water to reach full expansion. This suggests that polymers may require the presence of free water for quick expansion. Therefore, when polymers are used, it may be helpful to water the plants before the medium becomes very dry.

The absorbency and expansion of Aquasoil® and Stocko-sorb® polymers are seriously affected by fertilizer solutions. The nutrients used in this particular experiment were the main plant macro and micro nutrient ions. In growing plants, soils or growth media are amended with many of these nutrients. Therefore, practically the capacity of Aquasoil® and Stocko-sorb® polymers to retain water would probably be far below their maximum capacity. However, reduced absorption capacity of polymers due to salt solutions can be improved by rinsing them with water. Nonetheless, since the main aim of using polymers is to conserve water, many applications may be done where water is not available to flush the polymer if they become hydrophobic. Compared to some polymers shown in the literature, therefore, the relatively high absorption capacity under saline conditions is the most important property of Aquasoil® and Stockosorb® polymers.

References

ABRAHAM, J. & P1LLA1, V.N., 1995. N, N-methylene bisacrylamide-crosslinked polyacrylamide for controlled release urea fertilizer formulations. *Commun. Soil. Sci. Plant Anal.* 26, 3231-3241.

ALLCOCK, H.R. & LAMPE, F.W., 1990. Contemporary polymer chemistry. Prentice-Hall, Englewood Cliffs, New Jersey.

BAXTER, L. & WALTERS, L.Jr., 1986. Effect of hydrophilic polymer seed coating on the imbibition, respiration, and germination of sweet corn at four matric potentials. *J. Am. Soc. Hortic. Sci.* 111,517-520.

BOWMANS, D.C., EVANS, R.Y. & PAUL, J.L., 1990. Fertilizer salts reduce hydration of polyacrylamide gels and affect physical properties of gel-amended container media. *J. Am. Soc. Hortic. Sci.* 115,382-386.

FLANNERY, R.L. & BUSSCHER, J.W., 1982. Use of a synthetic polymer in potting soils to improve water holding capacity. *Commun. Soil. Sci. Plant Anal.* 13, 103-111.

FOSTER, W.J. & KEEVER, GJ., 1990. Water absorption of hydrophilic polymers (hydrogels) reduced by media amendments. *J. Environ. Hortic.* 8, 113-114.

FRY, J.D. & BUTLER, J.D., 1989. Water management during tall fescue establishment. *HortScience* 24, 79-81.

GEHRING, J.M. & LEWIS, A.J., 1980. Effect of polymer on wilting and moisture stress of bedding plants. *J. Am. Soc. Hortic. Sci.* 105,511-513.

HENDERSON, J.C. & HENSLEY, D.L., 1985. Ammonium & nitrate retention by hydrophilic gel. *HortScience* 20, 667-668.

HENDERSON, J.C. & HENSLEY, D.L., 1986. Efficacy of hydrophilic gel as a transplant aid. *HortScience* 21, 991-992.

JAMES, E.A. & RICHARDS, D., 1986. The influence of iron sources on the water holding properties of potting media amended with water absorbing polymers. *Sci. Hortic.* 2, 201-208.

JOHNSON, M.S., 1984a. Effect of soluble salts on water absorption by gel-forming soil conditioners. *J. Sci. Food Agric.* 35, 1063-1066.

JOHNSON, M.S., 1984b. The effect of gel-forming polyacrylamides on moisture storage in sandy soils. *J. Sci. Food Agric.* 35, 1196-1200.

LAMONT, G.P. & O'CONNELL, M.A., 1987. Shelf life of bedding plants as influenced by potting media and polymer. *Sci. Hortic.* 31, 141-149.

MAGALHAES, J.R., WILCOX, GE., RODR1GUES, F., S1LVA, F.L.l.M. & ROCHA, A.N., 1987. Plant growth and nutrient uptake in hydrophilic gel treated soils. *Commun. Soil. Sci. Plant Anal.* 18, 1469-1478.

MIKKELSEN, R.L., 1995. Using hydrophilic polymers to improve uptake of manganese fertilizers by soybeans. *Fert. Res.* 41, 87-92.

SAS Institute. 1999. Proprietary software release 8.2. SAS institute Inc., Cary, NC, USA.

TAYLOR, K.C. & HALFACRE, R.G, 1986. The effect of hydrophilic polymer on media water retention and nutrient availability to *Ligustrum lucidum. HortScience* 21,1159-1161.

T1SDALE, S.L. & NELSON, W.L., 1975. Soil fertility and fertilizers. Macmillan, New York.

WANG Y.T., 1989. Medium and hydrogel affect production and wilting of tropical ornamental plants. *HortScience* 24, 941-944.

WANG Y.T. & GREGG L.L., 1990. Hydrophilic polymers - their response to soil amendments and effect on properties of soil less potting mix. *J. Am. Soc. Hortic. Sci.* 115, 943-948.

WOODHOUSE, J.M. & JOHNSON, M.S., 1991. Effects of soluble salts and fertilizers on water storage by gel forming soil conditioners. *Acta Hortic.* 294, 261-269.