EFFECTS OF POLYACRYLAMIDE ON ESTABLISHMENT AND GROWTH OF CRESTED WHEATGRASS SEEDLINGS AND SAGEBRUSH TUBELINGS

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ABSTRACT

Experiments employing two forms (cross-linked and non-cross-linked) of polyacrylamide (PAM) at 0.2 percent, mixed with a silt loam Xerollic Calciorthid top soil, were performed in 1991. Larger cracks and lower mean penetrometer resistance occurred in the two PAM treatments compared to the untreated control. The two kinds of PAM failed to produce significant differences in soil moisture or crested wheatgrass (Agropyron desertorum) *germination. One-year-old tubelings of big sagebrush* (Artemisia tridentata) *did not grow significantly faster or flower significantly sooner or more abundantly than the untreated controls.*

INTRODUCTION

Arid or semiarid rangeland environments are characterized by limited soil moisture, poor water-holding capacity, high evaporation, and low soil organic matter (Stoddart and others 1975). Besides lack of rainfall, crust formation, vesicular structure, physical degradation of the soil surface, and high erodibility and runoff are also some of the main problems limiting rangeland production (Singer 1991; Wood 1988).

Crust formation on soil surfaces is due to a combination of three primary mechanisms (Agassi and others 1981, 1985; Paul and Clark 1989): (1) loss of soil organic matter; (2) the effect of raindrop impact energy, which causes a disintegration of the soil aggregates and compaction; and (3) the dispersion of clay particles at the soil surface. Taylor (1962) reported that in semiarid or arid environments, rapid and highly rigid crust development is enhanced by high evaporation demand, and rapid drying of the soil surface. Crusts impair seedling emergence and plant establishment (Shainberg and others 1990; Wood and others 1982). Crusting also leads to increased runoff and erosion, followed by a reduction in infiltration (Agassi and others 1985; Morin and others 1981; Shainberg and others 1990).

Water and wind erosion are another serious problem in rangeland environments (Singer 1991). Poor structure, low organic matter content, and the presence of salts (especially Na) lead to some of the common problems in arid environments such as high wind and water erodibility (Singer 1991). The soil surfaces in arid environments are easily moved by wind because of lack of surface soil moisture and sparse or nonexistent vegetation protection (Singer 1991).

One possible solution to overcome these rangeland limitations is the use of soil conditioners. Following some initial enthusiasm for soil conditioners in the early 1950's when the Monsanto Chemical Company marketed a patented chemical compound named "Krilium," interest declined because of the uncertainty of the outcome of cost-benefit analysis over a wide range of crops and climates. Recently, two symposia were held, one in Ghent, Belgium, in 1975 (De Boodt 1975), and one in Las Vegas, NV, U.S.A., in 1973 (Gardner and Moldenhauer 1975). Also, an entire issue of "Soil Science" was recently devoted to the subject in 1986 (Volume 141). These events occurred after improved formulations of more appropriate polymers invited reexamination of their utility.

Newer soil conditioners have been shown to improve seedling emergence, establishment, growth, and survival (Callaghan and others 1988; Cook and Nelson 1986; Helalia and Letey 1989; Rubio and others 1989, 1990; Wallace and Wallace 1986a, b; Woodhouse and Johnson 1991). However, Hamilton and Lowe (1982) reported decreased germination of tobacco with high levels of polymer application because of crusting. Synthetic conditioners have also been shown to reduce penetrometer resistance (Cook and Nelson 1986; De Boodt 1975; Helalia and Letey 1989; Rubio and others 1989, 1990; Steinberger and West 1991; Terry and Nelson 1986; Wallace and Wallace 1986b), and evaporation, especially in soils with coarse textures (De Boodt 1975; Rubio and others 1990; Woodhouse and Johnson 1991). They also improve some important soil physical properties such as bulk density and aggregate stability (Terry and Nelson 1986), and improve infiltration (Ben-Hur and others 1989; Mitchell 1986; Shainberg and others 1990; Smith and others 1990; Terry and Nelson 1986), leading, in some cases, to reduced soil erosion (De Boodt 1975; Gabriels and De Boodt 1975; Smith and others 1990; Wallace and Wallace 1986c). Some of these soil conditioners are capable of absorbing large amounts of water (Johnson 1984a; Woodhouse and Johnson 1991). Callaghan and others (1988) reported that a synthetic soil conditioner called polyvinyl alcohol almost doubled the field capacity of sandy soil when added at a concentration of 0.5 percent.

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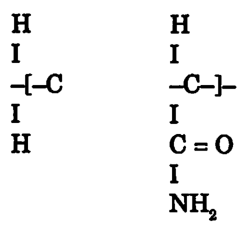
Most of the work done with soil conditioners has concentrated on agronomic and horticultural soils (Ben-Hur and others 1989; Cook and Nelson 1986; Terry and Nelson 1986; Wallace and Wallace 1986a). There are very few studies on the use of soil conditioners in rangeland soils (Rubio and others 1989, 1990; Steinberger and West 1991). Even if conditioners stay expensive, there are good possibilities in using them in appropriate rangeland contexts such as mined land reclamation, campgrounds, snow or sand barriers, and roadside revegetation.

The objectives of these studies were to investigate during the 1991 growing season the effects of two kinds of polyacrylamide (cross-linked and non-cross-linked) on crested wheatgrass (*Agropyron desertorum*) germination, big sagebrush (*Artemisia tridentata*) tubeling growth, and soil cracking, soil crusting, and soil moisture.

MATERIALS AND METHODS

Polyacrylamide (PAM) is a synthetic soil conditioner that is prepared by acrylamide polymerization (Azzam 1980). The unit structure of PAM is:



Non-cross-linked PAM, (hereafter designated as NC-PAM), trade named "Complete Green" (CG), is an anionic (relatively lower charged) polyacrylamide with a molecular weight of 10-15 x 10^6g/mol (Aly and Letey 1988). This polyacrylamide was obtained from Complete Green Company (Los Angeles, CA).

Cross-linked PAM (hereafter designated CL-PAM) is a very persistent conditioner with a high salt-buffering capacity. It can absorb water up to 40 and 500 times its own weight (Johnson 1984b). This polyacrylamide is also anionic and possesses relatively higher charges. It was obtained from Western Polyacrylamide Inc. (Castle Rock, CO).

Experiment 1

The purpose of this study was to evaluate the effects of PAM on seedling emergence, growth, and survival of crested wheatgrass. Topsoil from a silt loam Xerollic Calciorthid from a Curlew Valley site (Bjerregaard and others 1983) was thoroughly mixed with PAM (0.2 percent by weight) in a cement mixer for 40 minutes. The mixture was then applied in trenches (10 cm wide, 11 cm deep, 270 cm long) on which the seeded furrow was centered. Four replications of each treatment were used. Some furrows received 0.0 PAM (controls). The same numbers of pure live seed of crested wheatgrass were sown in each furrow on June 9. The plot was then sprinkled with well water to saturation on June 9. Germination (percentage of pure live seed emerging) and growth and survival (percentage of plants surviving by the end of the experiment) were monitored daily for the first 2 weeks and less frequently for the remainder of the growing season. Growth rate was monitored by counting new leaves and height progression of the plants. Weeds on these beds were eliminated weekly through hand cultivation.

Soil moisture was monitored by using time-domain reflectometry (TDR) (Topp and others 1984). Twenty conductors (25 cm long and 5 cm apart) were randomly placed horizontally throughout each trench. Readings of soil water content were taken at times of initiation and the dates listed in table 1.

Volumetric water content (Θ) was calculated following Topp and others (1984):

$$\Theta = -0.053 + 0.0292\,Ka - 5.5\text{x}10^{-4}\,Ka^2 + 4.3\text{x}10^{-6}\,Ka^3$$

where Ka is the apparent dielectric constant.

$$Ka = (ctL)^2$$

where L is the length of the conductor (mm), c is the velocity of an electromagnetic signal in free space (300 mm/nsec), and t is the travel time of the voltage pulse as measured by TDR (nsec).

The strength of soil crust was measured in the field by a hand-held penetrometer (Brandfort 1986) at 19 random points on each furrow. Soil cracking was quantified following the techniques used by Steinberger and West (1991). Two random sections (10 by 32 cm) in each furrow were photographed using a Polaroid Spectrum System camera. Photographs were analyzed using a digitized image computer analysis program (Sigma-Scan). Length and area of each crack was calculated, then the area was divided by the length to get a comparison between treatments.

Experiment 2

This study was carried out to evaluate the effects of PAM on shrub tubeling growth and survival. Two raised beds (2.4 by 1.8 m and 0.6 m deep) were constructed using railroad ties and filled with the soil from Curlew Valley. PAM (0.2 percent by weight) was mixed with the soil for 40 minutes in a cement mixer and deposited in an augured hole (10 cm wide and between 10 and 50 cm deep). The remainder of the hole and all the control holes were filled with untreated soil and then compacted to densities similar to those in the beds as a whole. Beds were sprinkled with well water on May 7, 1991, before transplanting, to start with a saturated soil.

Table 1—Dates at which the soil moisture readings were taken via TDR methods for both experiments 1 and 2

Reading number	Date taken
1	June 10, 1991
2	June 30, 1991
3	July 5, 1991
4	Aug. 22, 1991
5	Aug. 28, 1991
6	Sept. 4, 1991
7	Sept. 12, 1991
8	Sept. 15, 1991

One-year-old shrub tubelings of big sagebrush were transplanted to equidistant points on a grid having PAM or control soils underneath in both beds on May 12, 1991. Tubelings were grouped into similar size and vigor classes, and then one of each class was randomly assigned to each bed and location within the bed. Each plant received 1,000 ml of water at the time of planting. Nine replications of each treatment were started, but some died or were consumed by insects. Weeds on these beds were eliminated weekly through cultivation. The growth rate, phenological progression, and survival of the shrubs were monitored weekly throughout the growing season.

Soil moisture was monitored under each plant in each bed using TDR. Four conductors (two 25 cm and two 45 cm long and 5 cm apart) were placed vertically under each shrub. Moisture readings were taken by TDR periodically throughout the experiment (table 1). At the end of the experiment, the shrubs were harvested to obtain dry biomass. Cut portions of shrubs were placed in an oven for 24 hours under 48 °C. The roots were also extracted by washing the soil and root mass between the depth of 25 cm and 45 cm using a sieve (4 mm in diameter). The extracted roots were ovendried at 48 °C for 24 hours.

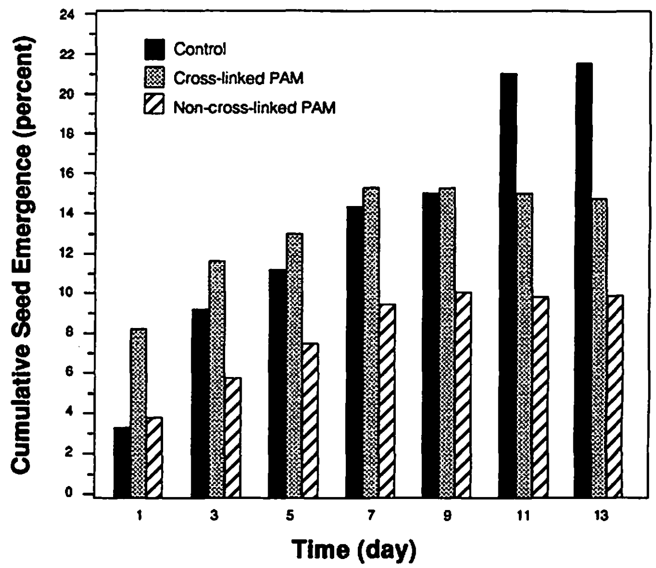


Figure 1—Cumulative seedling emergence of crested wheatgrass as influenced by two PAM conditioners.

EXPERIMENT 1 RESULTS

Effect of Two PAM Conditioners on Cracking and Penetrometer Resistance—Detailed data on the area/length cracking ratio and penetrometer resistance on the soil surface are shown in table 2. The area/length cracking ratio on the soil surface in CL-PAM treatments was significantly (99 percent confidence level) greater than that of the control and NC-PAM treatments. However, there was no significant difference between NC-PAM and control treatments. The CL-PAM amendment involves crystals that absorb water and swell. As evaporation takes place, soil surface shrinks back, leading to a greater chance of cracking.

The mean penetrometer resistance data show that the surface of the soil crust in the controls had the greatest soil strength (table 2). Both CL and NC-PAM treatments yielded similar less-strong crusts.

Effects of Two Soil Conditioners on Seeding Emergence and Soil Moisture—Seeding emergence of crested wheatgrass was recorded over a 2-week period (fig. 1). Crested wheatgrass seedlings emerged well, both with and without PAM applications, and no significant differences were found among treatments. An invasion of grasshoppers prevented us from following further grass growth past August 2, 1991.

Table 2—The influence of two PAM conditioners on penetrometer resistance (kg/cm^2) and cracking (numbers within parentheses are standard deviations from the mean[1]

	Treatment	Replications 1	2	3	4	Mean
Penetrometer Resistance (kg/cm^2)	Control	2.969 (0.877)	2.201 (0.713)	1.856 (1.117)	2.125 (0.753)	2.288
	Cross-linked PAM	0.739 (0.36)	1.062 (0.547)	1.291 (0.607)	1.154 (0.575)	1.062
	Non-cross-linked PAM	1.335 (0.238)	1.724 (0.537)	l.796 (0.531)	l.604 (0.513)	1.615
Cracking Area/length ratio	Control	0.345 (0.115)	0.245 (0.314)	0.538 (0.312)	0.432 (0.302)	0.390
	Cross-linked PAM	0.447 (0.321)	0.808 (0.464)	0.896 (0.307)	0.758 (0.369)	0.735
	Non-cross-linked PAM	0.434 (0.171)	0.658 (0.229)	0.436 (0.311)	0.467 (0.153)	0.499

[1]LSD (0.01) = 0.159 mean treatment for penetrometer resistance; LSD (0.01 = 0.211 mean treatment, for cracking.

In view of the pronounced soil crusting in the control soil, it was surprising that there was no significant difference in crested wheatgrass seedling emergence among treatments. Contrary to the expectation, seedling emergence was higher on controls (but not significantly) than PAM-treated plots.

Soil moisture content data are presented in figure 2. There were no overall significant differences among treatments in terms of soil moisture. There were, however, fluctuations of moisture level in soils during the 3 months because there were rainfall events on certain days, particularly August 28 and September 12. For this reason, significant differences in soil moisture level were observed among days on all treatments. In view of the pronounced soil cracking on CL-PAM plots, it was surprising that there were no significant differences in soil moisture or water availability among treatments.

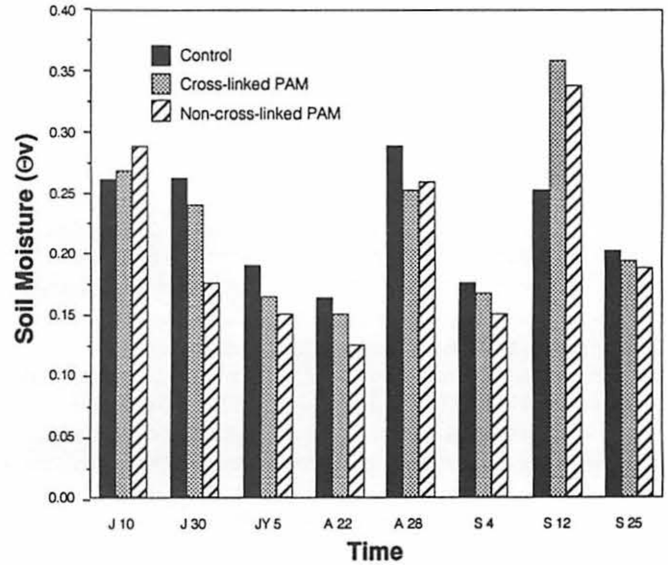


Figure 2—Effect of two PAM amendments on soil moisture content. (J = June; JY = July; A = August; S = September).

EXPERIMENT 2 RESULTS

Effect of Two PAM Conditioners on Soil Moisture—Soil moisture content over 3 months decreased from the first day of measurement to the last day of measurement (fig. 3). There were no significant differences in soil moisture among treatments.

Effect of Two PAM Conditioners on Biomass—Dry big sagebrush aboveground biomass data (table 3) and belowground biomass (table 4) showed no significant differences among treatments. Phenological progression and flower and seed production (data not shown) were also not different between treatments.

SUMMARY AND CONCLUSIONS

Effects of two PAM amendments at one level of concentration (0.2 percent) on one rangeland soil and two plant species were investigated. Soil cracking, penetrometer resistance, and moisture levels were investigated in the field. In addition, root density of big sagebrush and phenological progression, flowering, and fruiting were quantified.

Contrary to expectations from literature, the two PAM treatments did not improve total emergence of crested wheatgrass. Larger soil cracks were present in the two PAM treatments compared to the controls. The two PAM treatments also had lower penetrometer readings than the controls, showing the effect of these conditioners in ameliorating crusting. Both field experiments showed,

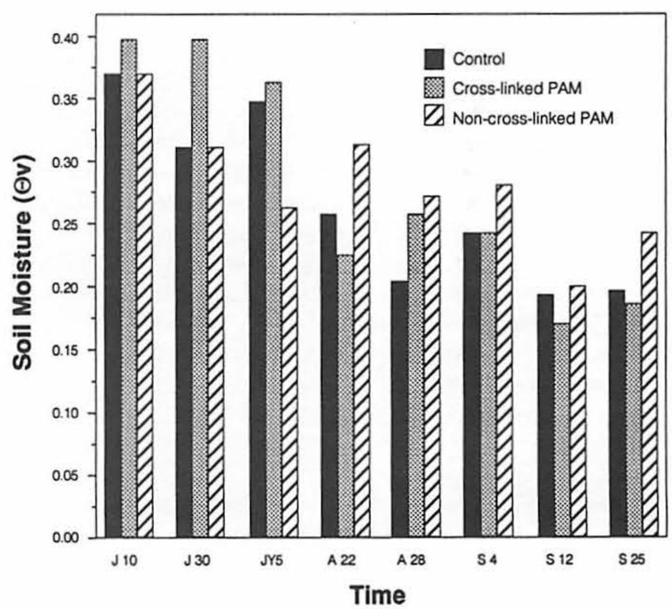


Figure 3—Effect of two PAM conditioners on soil moisture at 25 to 45 cm of depth. (J = June; JY = July; A = August; S = September).

Table 3—The effect of two PAM conditioners on sagebrush dry aboveground biomass (gm)

Treatments	Replications						
	1	2	3	4	5	6	7
Control	27.7	43.6	5.8	25.8	15.6	28.4	40.8
Cross-linked PAM	6.4	47.8	0.6	42.5	9.5	9.1	57.3
Non-cross-linked PAM	32.6	42.0	14.6	4.4	12.6	56.7	50.7

Table 4—The effect of two PAM conditioners on sagebrush dry root biomass (gm)

Treatments	Replications 1	2	3	4	5	6	7	8	Mean
Control	1.4	0.8	1.1	1.9	0.3	0.3	0.97	([1])	0.97
Cross-linked PAM	0.1	0.3	0.6	1.1	2.8	0.7	2.8	2.9	1.41
Non-cross-linked PAM	2.8	3.1	0.4	0.05	0.6	2.9	2.8	1.8	1.81

[1]Missing data; plant defoliated by harvester ants on June 24, 1991.

however, that the two PAM conditioners did not improve soil moisture or have any significant effect on sagebrush tubeling growth, phenological progression, flowering, seed production, and root density. Sample sizes in both experiments were small and variances high, and thus, Type II errors may have been incurred.

Any future studies of PAM conditioners should employ increased sample sizes and take into consideration different application rates of these synthetic conditioners. Further chemical properties of soil also should be tested for interactions with PAM.

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REFERENCES

Agassi, M.; Shainberg, I.; Morin, J. 1981. Effect of electrolyte concentration and soil sodicity on infiltration rate and crust formation. Soil Science Society of America Journal. 45: 848-851.

Agassi, M.; Morin, J.; Shainberg, I. 1985. Effect of raindrop impact energy and water salinity on infiltration rates of sodic soils. Soil Science Society of America Journal. 49: 186-190.

Aly, S. M.; Letey, J. 1988. Polymer and water quality effects on flocculation of montmorillonite. Soil Science Society of America Journal. 52: 1453-1458.

Azzam, R. A. I. 1980. Agricultural polymers, polyacrylamide preparation, application and prospects in soil conditioning. Communications in Soil Science and Plant Analysis. 11: 767-834.

Ben-Hur, M.; Faris, J.; Malik, M.; Letey, J. 1989. Polymers as soil conditioners under consecutive irrigations and rainfall. Soil Science Society of America Journal. 53: 1173-1177.

Callaghan, T. V.; Abdelnour, H.; Lindley, D. K. 1988. The environmental crisis in the Sudan: the effect of water-absorbing synthetic polymers on tree germination and early survival. Journal of Arid Environments. 14: 301-317.

Cook, D. F.; Nelson, S. D. 1986. Effect of polyacrylamide on seedling emergence in crust forming soils. Soil Science. 141: 328-333.

De Boodt, M. 1975. Use of soil conditioners around the world. In Soil conditioners. Spec. Publ. 7. Madison, WI: Soil Science Society of America: 1-12.

Gabriels, D.; De Boodt, M. 1975. Erosion reduction factors for chemically treated soils: a laboratory experiment. In: Soil conditioners. Spec. Publ. 7. Madison, WI: Soil Science Society of America: 95-102.

Gardner, W. R.; Moldenhauer, W. C., eds. 1975. Soil conditioners. Spec. Publ. 7. Madison, WI: Soil Science Society of America: 186 p.

Hamilton, J. L.; Lowe, R. H. 1982. Use of a water absorbent polymer in tobacco seedling production and transplanting. Tobacco Science. 26: 17-20.

Helalia, A. M.; Letey, J. 1989. Effects of different polymers on seedling emergence, aggregate stability, and crust hardness. Soil Science. 148: 199-203.

Johnson, M. S. 1984a. The effects of gel-forming polyacrylamides on moisture storage in sandy soils. Journal of the Science of Food and Agriculture. 35: 1196-1200.

Johnson, M. S. 1984b. Effect of soluble salts on water absorption by gel-forming soil conditioners. Journal of the Science of Food and Agriculture. 35: 1063-1066.

Mitchell, A. R. 1986. Polyacrylamide application in irrigation water to increase infiltration. Soil Science. 141: 353-358.

Morin, J.; Benyamini, Y.; Michaeli, A. 1981. The effect of raindrop impact on the dynamics of soil surface crusting and water movement in the profile. Journal of Hydrology. 52: 321-335.

Paul, E. A.; Clark, F. E. 1989. Soil microbiology and biochemistry. San Diego, CA: Academic Press. 273 p.

Rubio, H. O.; Wood, M. K.; Cardenas, M.; Buchanan, B. A. 1989. Effect of polyacrylamide on seedling emergence of three grass species. Soil Science. 148: 355-360.

Rubio, H. A.; Wood, M. K.; Cardenas, M.; Buchanan, B. A. 1990. Seedling emergence and root elongation of four grass species and evaporation from bare soil as affected by polyacrylamide. Journal of Arid Environments. 18: 33-41.

Shainberg, I.; Warrington, D. N.; Rengasamy, I. P. 1990. Water quality and PAM interactions in reducing surface sealing. Soil Science. 149: 301-307.

Singer, M. J. 1991. Physical properties of arid region soils. In: Skujins, J., ed. Semiarid lands and deserts: soil resource and reclamation. New York: Marcel Dekker: 81-109.

Smith, H. F. C.; Levy, G. J.; Shainberg, I. 1990. Water-droplet energy and soil amendments: effect on infiltration and erosion. Soil Science Society of America Journal. 54: 1084-1087.

Steinberger, Y.; West, N. E. 1991. Effects of polyacrylamide on some biological and physical features of soil: preliminary results from a greenhouse study. Arid Soil Research and Rehabilitation. 5: 77-81.

Stoddart, L. A.; Smith, A. D.; Box, T. W. 1975. Range management. 3d ed. New York: McGraw-Hill. 532 p.

Taylor, H. M. 1962. Seedling emergence of wheat, grain sorghum, and guar as affected by rigidity and thickness of surface crusts. Soil Science Society of America Proceedings. 26: 431-433.

Terry, R. E.; Nelson, S. D. 1986. Effects of polyacrylamide and irrigation method on soil physical properties. Soil Science. 141: 317-320.

Topp, G. C.; Davis, J. L.; Bailey, W. G.; Zebchuk, W. D. 1984. The measurement of soil water content using a portable TDR hand probe. Canadian Journal of Soil Science. 64: 313-321.

Wallace, A.; Wallace, G. A. 1986a. Effects of soil conditioners on emergence and growth of tomato, cotton, and lettuce seedlings. Soil Science. 141: 313-316.

Wallace, A.; Wallace, G. A. 1986b. Effect of polymeric soil conditioners on emergence of tomato seedlings. Soil Science. 141: 321-323.

Wood, M. K. 1988. Rangeland vegetation-hydrologic interactions. In: Tueller, P. T., ed. Vegetation science applications for rangeland analysis and management. Dordrecht, Netherlands: Kluwer Academic Publishers: 469-491.

Wood, M. K.; Eckert, R. E., Jr.; Blackburn, W. H.; Peterson, F. F. 1982. Influence of crusting soil surfaces on emergence and establishment of crested wheatgrass, squirreltail, thurber needlegrass, and fourwing saltbush. Journal of Range Management. 35: 282-287.

Woodhouse, J. M.; Johnson, M. S. 1991. The effect of gel-forming polymers on seed germination and establishment. Journal of Arid Environments. 20: 375-380.