Appl Biochem Biotechnol (2011) 163:780–791
DOI 10.1007/s12010-010-9082-1

Studies on Amendment of Different Biopolymers in Sandy Loam and Their Effect on Germination, Seedling Growth of *Gossypium herbaceum* L.

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Received: 20 March 2010 / Accepted: 7 September 2010 /
Published online: 22 September 2010

Abstract Different biopolymers, agar, cellulose, alginate, psyllium gaur gum, and bacterial exopolysaccharide (EPS) powders were amended to check their efficacy in enhancing maximum water holding capacity (MWHC), permanent wilting point (PWP), and germination and seedling growth of the *Gossypium herbaceum* in a laboratory scale. The efficacy of all biopolymers for enhancement of MWHC, PWP, and growth was also analyzed by measuring organic carbon, organic matter, total nitrogen, respiration rate, and microflora in amended and control sandy loams. The range of concentrations (0.2–2%) of all biopolymers was incorporated in sandy loam containing pots. The soil without polymer was considered as control. The psyllium (0.6%) and bacterial EPS (1%) amended soil has 242 and 233% increase in MWHC and thus delaying in the permanent wilting point by 108 and 84 h at 37 °C, respectively, as compared to control. All biopolymers found to increase more or less MWHC, organic matter, total nitrogen, microflora, and PWP as compared to control. The psyllium and bacterial EPS show the highest increase organic matter, biomass, and microflora. The highest reduction in MWHC after 12 weeks were observed in cellulose, gaur gum, and alginate; besides, psyllium, bacterial EPS, and agar showed comparatively less reduction MWHC, i.e., 24% and 14.5%, respectively. The toxicity studies of biopolymer were carried out on earthworm (*Eisenia foetida*). It revealed their nontoxic nature. The biopolymer amendment in sandy loam can be an effective strategy to improved soil texture, fertility, and thereby crop yield.

Keywords Biopolymer · Psyllium · MWHC · PWP · *Gossypium herbaceum* L. · *Eisenia foetida*

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Introduction

Urban development and resource competition are increasingly forcing agricultural production to marginal land where modern irrigation technologies are essential for economic production levels. With irrigation, however, comes the age old problem of erosion, a constant threat to agricultural productivity and our environment. Soil runoff from furrowed irrigated fields removes 6.4 t of topsoil per acre per year on average [1, 2]. The arid soils generally erode easily because they tend to be low in organic acid and natural polysaccharides that provide structure and protect soil against shearing forces of running water [3, 4]. The physical property of soil directly affects crop productivity [5]. Soils of the coarse textured class often are poorly structured. Water application to such soils through irrigation or rainfall causes aggregate breakdown and undesirable physical conditions because of their weakly bonded aggregates [6]. This also leads to seal formation, decreased infiltration and increased runoff, low water, and nutrient bonding capacity because of high macropores [4, 5].

One of the highly effective methods to enhance and improve soil structure is addition of conditioners such as synthetic and natural polymers that improve soil cohesion, porosity, maximum water holding capacity (MWHC), and various beneficial soil properties. This has led to increased demands for the development of water-soluble polymeric soil conditioners. In various studies of conditioners, polyacrylamide (PAM)-based polymers or PAM polymers were identified as an effective class of soil stabilizers [7–14]. Synthetic polymers in the form of crystals or tiny beads are available under several trade names such as superabsorbent, soil care, root watering crystals, etc. These are hydrogels having enormous capacity to hold water and make it available to plant during hot days. Many studies related to application of hydrogel polymers in horticulture have been reported [15–18]. The addition of hydrogel at rate of 2 g/kg of soil increased the water holding capacity of coarse sand from 171% to 402% [19]. Hydrogel addition also improved water holding properties of arid and porous soil and resulted in the delay and onset of permanent wilting point (PWP) under intense evaporation. Increase in MWHC significantly reduced the irrigation requirement of various crops and prolong PWP of soil [20, 21]. Seed germination and establishments are critical phases in plant growth and development. Environmental and soil textural conditions play a key role in plant establishment [16]. Generally, in arid and sandy loam soils, seedlings are not established properly which directly affects plant growth as well as yield [22]. Application of soil conditioners containing hydrogel is an important remedy for coarse and arid soils, which assist plant growth by increasing water retention and its availability to plant in hot dry days. Wallace and Wallace [22] reported improvement in seedlings emergence rate and dry weight of tobacco and cotton after hydrogel amendment in arid sandy soils. Akhter et al. [23] also reported improvement in seeding growth of barley, wheat, and chickpea and also observed increase in water retention capacity of sandy loam and loam soil. Ahmed and Verplancke [24] observed improvement in germination and biomass production of *Trifolium* and lettuce after amendment of dune sand. PAM were recently shown to improve soil physical properties and soil aggregation [11, 12, 25].

Although polyacrylamide-based polymers have been reported to be successful in irrigation and soil management, alternatives are needed which overcome the short-comings like variation in efficacy in different soil types, high cost, and production using nonrenewable sources [26]. The increasing market pull of organic farming techniques is a strong reason to explore alternatives to PAM as they cannot be used during organic farming because of their synthetic nature and production from nonrenewable resources. There is strong correlation between microbial activity and some physical properties of polymers such as porosity and penetration resistance [3, 27].

Natural polymers that often degraded via relatively benign routes may be more suitable hydrogels for soil management. Orts et al. [28] reported use of xanthan and cellulose for reducing the soil erosion up to 80% when used at the rate of 80 ppm in irrigation water. Cost-effective and ecofriendly nature are important factors in success and economics of projects envisaging the rehabilitation of sandy, arid soils through increased crop establishment and productivity in the world. The objective of the present study was to find out the effect of biopolymers on MWHC, PWP, organic carbon, nitrogen, and microflora of sandy loam soil, toxicity to earthworms, and seedling growth of *Gossypium herbaceum* L., an important cash crop of Maharashtra state of India.

Materials and Methods

Biopolymers

Powdered biopolymers (agar agar, alginate, cellulose, gaur gum) with physiochemical properties mentioned in Table 1 were used as received (Hi-Media Laboratories Pvt. Ltd, Mumbai). Psyllium husk powder (SATNAM Psyllium Industries, Mehsana, Gujrat, India) was used after purification which was done by precipitation from aqueous solution with alcohol and finally washed with acetone. Bacterial exopolysaccharide was produced by fermentation using *Azotobacter indicus* ATCC 9540 as described earlier [29].

Soil, Seeds, and Water

Sandy loam soil samples were collected from 20 cm depth at site by Latin square fashion method [30]. The soil samples were air-dried, ground, and sieved by using 2-mm sieves. Soil texture was determined by sedimentation technique [31]. The pH and conductivity of soil saturated extract was determined by using a pH meter (PICO LabIndia) and conductivity meter (Systronics, India), respectively (Table 2). Seeds of a local variety of *G. herbaceum* L. grown in North Maharashtra region were used. Tap water was used throughout all the experiments having EC 0.447 dS/cm, TDS 284.5 ppm, temperature 30 °C, and pH 7.2.

Table 1 Physicochemical characteristics of biopolymer

Description	Agar	Alginate	Gaur gum	Cellulose	Bacterial EPS	Psyllium husk
Source	Algae	Algae	Plant	Plant	*Azotobacter indicus*	*Plantago ovata*
Color	Cream	White to yellowish	Cream	Off white	Cream	Faint cream
Nature	Homogenous	Homogenous	Homogenous	Homogenous	Homogenous	Homogenous
Consistency	Free flowing powder	Free flowing granular powder	Free flowing powder	Free flowing powder	Free flowing powder	Mucilaginous powder
Moisture (%)	6.5	7.8	5.6	5.7	7.8	8.5
Solubility	Hot water	Water	Slightly soluble in water	Hot water	Alkaline water	Swell in water
Carbohydrate (%)	99	98	97	98	97.7	96
Protein (%)	0.15	0.16	0.13	0.15	2.3	3.0
Swell volume (ml/g)	25	15	10	11	19	45
Total ash (%)	6.5	5.5	5.6	6.2	6.1	4

Table 2 Characteristics of sandy loam soil used in experiments

SN	Parameter	Result
1	pH	8.3
2	EC (dS cm^{-1})	1.27
3	Clay (%)	20
4	Silt (%)	15
5	Sand (%)	65
6	MWHC	27.77

Maximum Water Holding Capacity of Soil

MWHC of soil was determined after different wetting cycles using Piper method [32]. Different samples of soil with and without polymers were filled and uniformly packed in keen Roczkowski box and weighed (*X*). Then boxes (with soil) were kept in tray having water up to 1 cm level and allowed to saturate for 24 h. Boxes were taken out from tray, wiped them to dry from outside, and allowed to drain for 30 min. Their weight after saturation (*Y*) was recorded. The saturated soil was dried in an oven, cooled in dessicator, and weighed (*Z*). Water absorbed by filter paper was determined by weighing filter paper of same size as fitted in keen box. The filter papers were saturated with water, gently rolled with a glass rod over to squeeze out water uniformly. Weight was taken again and the average amount of water held by one paper (*W*) was calculated. Each experiment was carried out in triplicate.

$$\mathrm{MWHC}(\%) = \frac{Y - Z - W}{Z - X} \times 100$$

Porosity of Soil

Effect of biopolymer amendment on soil porosity was determined by analyzing particle and bulk density of amended soil [30]. Porosity was determined by using following formula,

$$\mathrm{Porosity} = 1 - \frac{\mathrm{Particle\ density}}{\mathrm{Bulk\ density}} \times 100$$

Microbial Count

Total microbial count of soil after biopolymer amendment in each treatment vis-à-vis control soil without treatment was determined by microbiological plate count technique [33]. Briefly, amended soil samples after 25 days were serially diluted in sterile saline, 10^{-7} and 10^{-4} dilutions were plated on plate count agar and incubated at 37 °C for 24 h, and colony-forming units (CFU) were recorded.

Respiration Rate

In order to assess the rate of microbial activity in the cups during the incubation period, the CO_2 release procedure, as an indicator of soil respiration rate, was used [34]. Briefly, a test tube with 10 ml of 0.1 N NaOH was placed at the top of each bottle with amended soil and immediately made airtight. After 3 h, the entire contents of each container were transferred to an Erlenmeyer flask by washing twice with 10 ml of distilled water and titrated with HCl (0.1 N). These procedures were also repeated for a sterile soil (blank). The soil respiration rate was calculated as follows:

$$\text{mg of } CO_2 \text{ Pot}^{-1}\ 3\ \text{h}^{-1} = (B - V) \times N \times 22$$

where B and V are the volume of HCl used for the blank and soil samples (milliliters), respectively, N is the normality of HCl, and 22 is the gram equivalent of released CO_2.

Organic Carbon

Increase in total organic carbon due to biopolymer amendment was determined by dichromate method [35]. The soil samples of different amendments were taken after 25 days incubation.

Total Nitrogen

Effect of biopolymer amendment on nitrogen content of soil was determined by micro-Kjeldahl method [36]. Briefly, the organic nitrogen converted into ammonia, trapped into borate, and this salt was titrated with acid and total nitrogen was calculated per kilogram of soil. Soil sample of test was used after incubation of 25 days.

Effect of Biopolymer Addition on Germination and Seedling Growth

The biopolymers were mixed at the rate of 0.1–2% in air-dried sandy loam. Two-hundred grams of each soil mixture (concentrations ranging from 0.1 to 2%) was filled in different 300-ml capacity plastic cups with hole at bottom covered by filter paper. Ten seeds of *G. herbaceum* L. were sown in each cup. The soil without biopolymer amendment was kept as control. Soils in the cups were saturated for 24 h with water by placing in tray with water level up to 1 cm and excess water was removed gravimetrically. After incubation of 25 days, biomass in terms of fresh and dry weight, shoot length of plants was measured.

Permanent Wilting Point

PWP was determined by Breazeale and McGeorge method [37]. Biopolymers were mixed at the rate of 0.1–2% in soil. Five hundred grams of each biopolymer–soil mixture was filled in 700-ml capacity plastic cups. Filter papers were placed at the bottom of every cup with small hole at the center. Soil in each of the cups was saturated with water for 24 h by placing them in tray containing tap water up to 1 cm level, and excess water was removed gravimetrically. Ten numbers of seeds of *G. herbaceum* L. were sown in each cup and incubated at 25 °C and 37 °C separately. The weights of cups were taken three times weekly until no detectable weight loss was observed. No additional irrigation except initial saturation of cups was done. When the sign of wilting of seedling was appeared for the first time, the experiment was terminated. The soil without biopolymer amendment was treated as control. Moisture of soil at these conditions was recorded of all the test and control samples, and duration for wilting in control and test was recorded.

Experimental Design for Toxicity Testing of Biopolymer

Circular plastic containers/cups with diameter of 28 cm and depth of 24 cm were filled with 500 g of each polymer-amended soil material. The moisture content of polymer was adjusted to 70–80% during the study period by spraying adequate quantities of distilled water. The four young non-clitellated earthworms of species *Eisenia foetida*, weighing 200–250 mg each live weight, were randomly picked from several stock cultures and were introduced in each container with polymer-amended treatments and maintained in the laboratory. Soil without polymer was used as control. After 3 weeks, viability of *E. foetida* was checked in each treatment and recorded.

Data Analysis

Every experiment was run in three replicates. Separate controls were set in all the replicates. Mean values with standard deviation were represented in tables and graphs. Means were separated by multiple comparison analyses.

Results and Discussion

Effect on MWHC and Porosity

Addition of biopolymers increased the MWHC of sandy loam soil. Psyllium amendment showed very significant positive effect on increasing MWHC of the test soil. Addition of bacterial polymer and psyllium enhanced the water holding capacity by 233% and 242%, respectively (Table 3). The water holding capacity increased in concentration-dependent manner up to certain limit, i.e., 1% and 0.6% in case of bacterial polymer and psyllium, respectively. Further increase in concentration not showed significant increase in water holding capacity. Alginate and agar also showed significant improvement in water holding

Table 3 Microbial flora and physicochemical characters of amended sandy loam at optimized biopolymer concentration

Parameter	Control	Agar	Alginate	Guar gum	Bacterial polymer	Psyllium	Cellulose
MWHC (%; at initial stage)	27.6±0.1	62.42±0.35	63.33±0.25	53.33±0.21	64.60±0.21	67.13±0.26	55.51±0.25
MWHC (%; after 12 weeks)	26.6±0.26	50.80±0.65	35.13±0.41	32.13±0.41	43.83±0.20	51.56±0.51	31.5±0.4
Porosity	73.33±1.52	92.33±2.33	97±2	87±2	96±1	102.33±1.52	87.33±1.52
TVC (CFU)	1×10^3	4×10^4	4×10^5	2×10^2	4×10^4	6×10^5	5×10^5
CO_2 (mg/3h)	0.39±0.01	1.40±0.02	1.59±0.01	0.70±0.01	1.7±0.02	1.80±0.02	2.05±0.05
Total carbon (%)	0.15±0.01	0.72±0.02	0.84±0.02	0.42±0.01	1.15±0.05	0.94±0.02	0.83±0.02
Organic matter (%)	0.258±0.004	1.282±0.036	1.443±0.041	0.743±0.014	1.731±0.088	1.616±0.086	1.369±0.068
Total nitrogen (%)	0.090±0.001	0.103±0.002	0.111±0.003	0.096±0.005	0.17±0.002	0.18±0.01	0.116±0.005
pH	8.3±1	7.63±0.11	7.96±0.15	7.9±0.1	7.86±0.05	7.86±0.05	7.06±0.11
Moisture (%, 25 days)	3±0.0	14.33±1.52	15±1	12.33±0.57	15±1	17±2	9±1

Percentage of sand, silt, and clay in soil remains constant in all experimental sets, i.e., 65%, 15%, and 20%, respectively. All values are mean ± standard deviation capacity. Besides alginate, other polymers (gaur gum, cellulose) also positively affected MWHC of the test soil (Fig. 1). Alginate and gaur gum enhanced water holding capacity at the concentrations of 0.4% and 0.6%, respectively. As compared to other biopolymers, cellulose addition showed the least effect on MWHC of the test soil (Fig. 1).

In dry and semiarid environment, water retention capacity or moisture retention plays a key role in the growth and establishment of crops. McGuire et al. [38] observed that the use of soil conditioners improved the water holding or moisture holding capacity of soil. Lentz and Sojka [8] discussed the use of polyacrylamide as a soil conditioner, which improves the silt soils by improving MWHC and also reduces soil erosion. The synthetic soil conditioners like PAM, glycols, and hydrogel have major drawbacks like cost, carcinogenicity, sources of origin, etc. The soil conditioners like PAM are not used in organic farming due to their synthetic nature. Natural polymers that often degrade via relatively benign routes may be more suitable as soil conditioners. Effect of biopolymer amendment on porosity showed very significant results. Psyllium and bacterial polymer amendment showed comparatively highest increase in porosity, which was also proved by increase in water holding capacity, microbial count, and respiration (Fig. 1). The most effective concentration of psyllium and bacterial polymer was found to be 0.6% and 1%, respectively. Alginate showed comparable results and other biopolymer amendments showed slight increase in porosity (Table 3). These results are similar to previous reports, which proved strong correlation between microbial activity and some physical properties of soils such as porosity and penetration resistance [3, 27, 39, 40]. Figure 1 shows that psyllium and bacterial EPS treatments significantly increased MWHC and porosity. This indicates that it may be due to decrease in the macropores and significant increase in micropores. Similarly, Nyamangara et al. [4] and Warrick [41] reported significant increase in the respiration, percentage of mesopores, by decreasing macropores due to anionic PAM. These reports indicate PAM-modified aggregation of soil, soil respiration, soil water, and solute holding capacity. In the present study, similar trend was observed with psyllium amendment. Moreover, bacterial polymer and agar showed comparable results (Table 3). There is a strong correlation between respiration rate and the percentage of macropores in soil. Pagliai and Nobili [42] reported that soil enzymatic activity was generally related to the size of the soil microbial population and that it was positively influenced by the number of pores, ranging from 30 to 200 μm.

Uses of biopolymers like agar, alginates, gaur gum, and bacterial polymer may avoid drawbacks of synthetic soil conditioners. The amendment of biopolymers increased the MWHC of sandy loam soil and, in turn, of available water. Such increase in MWHC and

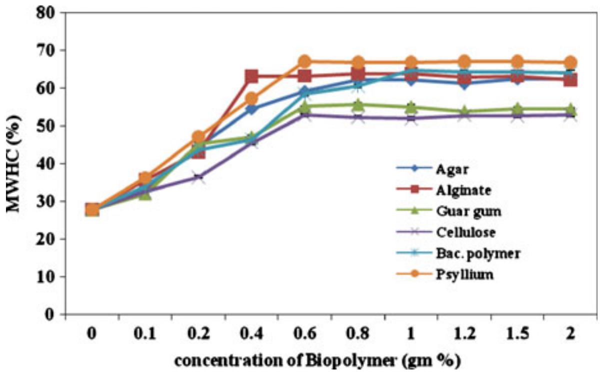

Fig. 1 Effect of biopolymer amendment on MWHC of sandy loam soil

field capacity has been reported for several soil types [20, 43, 44]. Diverse reports describe use of cellulose, starch, and xanthan to reduce soil erosion and improvement of seedling growth [28, 45–47]. After 12 weeks, reduction in MWHC in each biopolymer-amended soil was observed (Table 3). The highest reduction in MWHC was observed in cellulose, gaur gum, and alginate whereas psyllium and agar showed comparatively less reduction MWHC, i.e., 24% and 14.5%, respectively (Table 3). This may be due to susceptibility of cellulose and gaur gum to microbial degradation [48–50]. The absorption capacity of alginate and bacterial exopolysaccharide was affected during wetting cycles by presence of calcium and sodium ions in tap water or soil. Bowman et al. [51] reported similar phenomenon in case of polyacrylamide gel (PAG) application in soil that divalent cations of soluble salts reduce the ability of PAG to swell and absorb water.

Effect of Biopolymer Amendment on Microbial Count, Respiration Rate, Organic Carbon, and Total Nitrogen Content

Enhancement in microbial population was observed in all biopolymer amendments. These are very significant results than the previous reports on PAM amendment in soil. Sojka and Entry [52] reported that PAM treatment reduces total bacterial and microbial biomass and total fungal biomass relative to the control treatments. Increase in microbial population in natural polymer amendment was due to the high availability of organic carbon, good aeration, and moisture availability. This, consequently, might have increased the activity of soil microorganisms. Cellulose might be degraded by cellulolytic microbes and resulted in formation of reducing sugars, which leads to induction of high microflora, while high amino acid and carbohydrate content in psyllium husk may be favorable for microbial growth. Creation of good aeration conditions and the consequent availability of O_2 is an important factor in microbial aerobic decomposition [41, 53].

Appreciable increase in respiration rate after biopolymer treatments (Table 3) probably indicates all optimized concentration for MWHC and porosity were adequate. Among the biopolymer treatments, psyllium and cellulose indicated the highest respiration rate, which may be due to the high organic carbon content (Table 3). This was similar to previous reports of soil amendment with polymers and vermicompost to a silt loam soil [3, 54].

Organic carbon and nitrogen content was found to be increased very significantly in all biopolymer amendments. Carbon content was appreciably increased with amendment of psyllium and bacterial exopolysaccharide by 0.95% and 1.1%, respectively, while nitrogen content of soil was drastically increased by 0.180% with psyllium amendment followed by other polymers (Table 3). This may be result of increase in heterotrophic microbial population. Microbial count was notably increased in the soil amended with psyllium (6×10^5) and cellulose (5×10^5; Table 3). Parallel findings have been reported by Caesar-Tonthat et al. [40]. Kay-Shoemake et al. [39] found increase in concentrations of NO_3 and NH_3 and significant elevation in the number of heterotrophic bacteria after PAM amended in potato plot.

Effect on Germination and Seedling Growth

Seed germination and seedling development are critical phases in early growth and establishment of any plant. In dry and semiarid environment, water retention capacity or moisture retention plays key role in the growth and establishment of crops. Biopolymer addition showed significant effect on physical property of soil. It was observed that addition of biopolymers to sandy loam soil did not show any significant effect on germination of

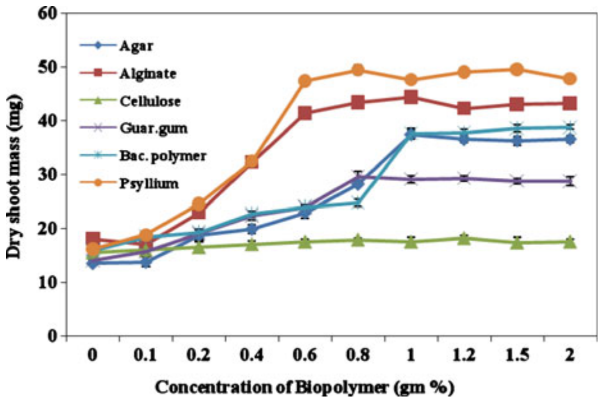

Fig. 2 Effect of biopolymer amendment on dry shoot mass of *G. herbaceum* L.

cotton seeds as compared to untreated soil. However, their addition showed potential effect on seedling growth and biomass production (Figs. 2 and 3). Akhter et al. [23] reported analogous effects with synthetic hydrogel amendment in sandy loam soil and loam soils amended with 0.3% PAG, fresh and dry weights of wheat shoots increased. They observed that hydrogel amendment did not affect germination of wheat and barley but improved seedling growth in chick pea.

These results are also in agreement with the previous observations like PAG amendments increased growth of greenhouse tomato grown in a podzolic soil [55] and lettuce [56]. Moreover, vegetative yields of wheat and tomatoes grown in a Xerothents soil were improved by adding 1% polymer [22]. Where evident, growth improvements may be attributed to improved soil moisture content and reduced evaporation losses from soil surface [22].

Psyllium amendment enhanced the growth of seedlings, i.e., shoot as well as biomass of *G. herbaceum* L. (Figs. 2 and 3). Alginate amendment also showed comparable results with psyllium and bacterial polymer. Conversely, urea-formaldehyde resin foam (UFRF) and PAG amendment neither shown increase in shoot fresh mass nor in dry weight of *Orthosiphon aristatusin* [57]. Nikolopoulou et al. [58] also observed that turfgrass root dry mass could even reduce upon UFRF amendment. For landscape rose, dry root and stem biomass were not improved by PAG [19]. Increase of biomass in certain polymer amendment indicates polymer makes available water to plant for long time.

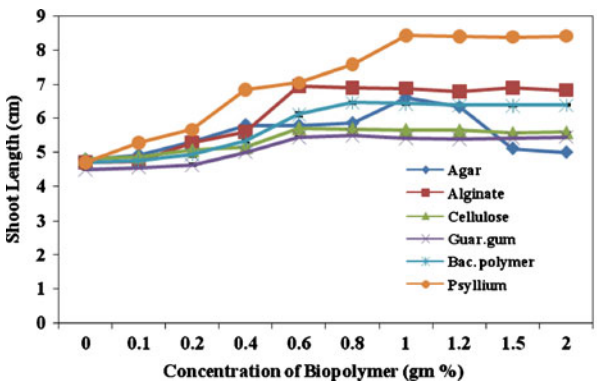

Fig. 3 Effect of biopolymer amendment on shoot length of *G. herbaceum* L.

Effect on PWP and Moisture Content

Use of biopolymer enhanced the water retention capacity and reduced the moisture loss which in turn influence delay in wilting of seedlings. Control soil showed PWP at 168 h at 25 °C. After 0.6% psyllium amendment, the onset of PWP was found at 288 h while in case of agar, alginate, bacterial polymer, guar gum, and cellulose amendment, PWP was 241, 240, 264, 218, and 216 h at 25 °C, respectively, at optimum concentration. Such delay in time to wilt reduced the water requirement of crop [20, 59]. In view to ensure suitability of biopolymers at field conditions, onset of PWP was also observed at 37 °C. Even in high temperature (37 °C) incubation, PWP increased by 108–28 h in each respective biopolymers at an optimum concentration compared to control (120 h). Maximum PWP at 37 °C found 228 and 200 h for bacterial exopolysaccharide and psyllium amendment, respectively.

These observations are agreement with Huttermann et al. [60], when they observed that *Pinus halepensis* in soil amended with 0.4% (*w*/*w*) PAG had almost double the survival time than control plants after water withhold, viz., 82 and 49 days, respectively. PAG amendment (0.4%, *w*/*w*) also enhanced drought tolerance of citrus plants and prolonged seedling survival under water stress conditions [61]. On the contrary, Nguyen et al. [57] observed inability of PAM and UFRF amendments for delaying PWP of *Orthosiphon aristatus*.

The increase in water availability with biopolymer addition is known to improve seed germination and seedling growth [22, 62]. Ahmed and Verplancke [24] documented variations in the response of different plant species to polymer products, which are used as soil conditioners. The soil amended with psyllium at concentration of 0.6% retained the maximum moisture content (17%) after 25 days, while other polymers like agar agar, gaur gum, and cellulose also showed increase in moisture as compared to control. Bacterial exopolysaccharide also showed analogous results with psyllium (Table 3). Cellulose was the least effective mainly because of its high susceptibility to cellulase producing microbes in soil [50, 63, 64].

Toxicity Testing

The toxicity testing carried out on earthworm showed that average mass of each earthworm was increased up to 650 mg after 4 weeks. This is comparable with previous report of mass gain of earthworm with use of suitable soil conditions [65]. These results advocate that all biopolymer amendments are beneficial and lead to development of suitable growth environments for *E. foetida*. It also reveals nontoxic and ecofriendly nature of biopolymers.

Conclusion

The results of present work give the evidence for the biopolymers with high water retention capacity. The water was retained in subsequent wetting and drying cycles. Biopolymer addition was nontoxic to earthworm and found to improve the maximum water holding capacity of soil and also the growth and establishment of crops in safe and economical way. Biopolymers can prove alternatives to PAM, PAG, and other synthetic conditioners. In addition, they have marketing advantages due to public perception of being safer. The use of biopolymers as soil conditioners in drought prone environment was more significant and useful. The choice of biopolymers for soil amendment needs to be made in accordance with the type of soil and the specific conditions existing in the field. However, extensive investigation on influence of various biopolymers in different soil types and crops will be needed for proper recommendations.

Acknowledgment Financial assistance of University Grant Commission, New Delhi, File No. 34-236/2008 (SR), under Major Research Project Scheme to SVP is gratefully acknowledged.

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