Enhancing the effectiveness of soil amendments using anionic polyacrylamide: A review

Abstract

The loss of soil amendments in plains and sloped locations with runoff water is a crucial problem. The diminution in the residence period of soil amendments in the soil affects their effectiveness. Due to non-cohesive character, most of the soil amendments such as biochar, lime, sulphur etc. erode with the soil on sloped surfaces. Ultimately, soil productively remains same before and after the application of soil amendments, which causes loss of time, money and labor. As per the available literatures, it was demonstrated that soil amendments must be applied with any cohesive ingredient in order to maximize their effects. Despite having a cohesive nature, gypsum has also been found to be disappearing from the field. An inexpensive, easily accessible, adaptable, and organic soil additive called anionic polyacrylamide (PAM) can be utilised to address these issues. PAM does not directly contribute to the growth of vegetation, but because of its organic and cohesive character, it gives significant stability to other soil amendments and promotes crop growth. In this review, the efficacy of biochar, gypsum, lime, and PAM is discussed both singly and in combination. Most importantly, effect of blending of important soil amendments such as biochar, gypsum and lime with the PAM was discussion to understand biomass growth, soil erosion, nutrient loss and enhancement of soil properties to promote soil productivity.

Keywords: Soil amendments; Biochar; Anionic polyacrylamide; Soil conservation; Soil productivity

1. Introduction

Soil erosion is one the major problem in plains as well as on hillslopes [1, 2, 3, 25]. On sloping surfaces, the rapid runoff and soil loss cause the loss of vital soil amendments like biochar, gypsum, lime, and sulphur from the field. To maintain soil physico-chemical properties and temperature, reduce soil erosion, and enhance soil productively several approaches were used in past [4, 5, 6, 24]. Most agronomic and engineering techniques are expensive, labor-intensive, or produce less-than-desired results. Some techniques are also not appropriate for all soil types [7]. One of the biggest issues is reducing soil erosion and amendment loss from sloping surfaces without impacting agricultural yield. Researchers are currently looking for affordable, accessible, adaptive, and organic soil additives that can bond soil amendments with soil and address issues with soil loss, amendment loss, and other associated issues in the field.

An organic soil supplement called anionic polyacrylamide (PAM) has a cohesive character. PAM binds the soil particles to prevent soil erosion and decreases the formation of seals [8, 9]. PAM in liquid form can easily penetrate the soil's pores and promote soil aggregation. PAM is also utilised as a water body cleaner by combining with the suspended particles in water bodies. PAM does not directly contribute to the growth of vegetation, but because to its organic nature, no adverse effects on the soil or plants have been documented by any researchers to date [10, 11]. After degrading, PAM releases a source of carbon and nitrogen and aids in the growth of vegetation. PAM decreases nutrient, runoff, and soil erosion losses, which in turn promotes vegetation growth.

PAM has been shown to have advantages when combined with other soil amendments in numerous studies. By using PAM and gypsum, Kumar and Saha [12] showed how to reduce soil erosion and runoff. Additionally, Kumar and Saha [12] discovered that applying gypsum with PAM produced better outcomes in the soil and more stable gypsum than applying gypsum alone. Kushwaha et al. [11] showed that a single biochar application increased biochar loss on sloping surfaces, which reduced the field benefits of using biochar. Kushwaha et al. [11] observed that applying biochar with PAM enhanced its stability in the soil and boosted its effectiveness in promoting biomass development.

Blending of PAM with other soil amendments could be beneficial to increase the time of residence and benefice effect of amendments in the soil. PAM can biodegrade into the soil on its own, however when PAM is applied with biochar then biochar speeds up this process [13]. Gypsum and PAM both have a cohesive nature in the soil, according to Kushwaha et al. [11], but PAM had more impacts than gypsum in terms of boosting biomass growth and lowering biochar loss. The effectiveness of biochar, gypsum, lime, and PAM in the soil has been explored in this paper in detail. The combined effect of biochar, gypsum, and lime with PAM was also covered in detail in this review.

2. Effectiveness of amendments in the soil

2.1 Biochar

With its multi-objective behaviour to satisfy farmer needs and handle environmental concerns, the biochar, an organic soil amendment, has emerged as the most effective. Biochar boosts soil productivity more effectively than other organic additions since it lasts in the soil for thousands of years [10, 11]. Biochar is an activated charcoal that contains high carbon, hydrogen, oxygen, nitrogen, and ash in varying amounts rather than pure carbon. According to Kushwaha et al. [11], biochar aids in reducing runoff, nitrogen loss, and soil erosion. The management of crop residue, which is a frequent issue for farmers for a variety of reasons, is made easier with the use of biochar. Biodecolorization of Remazol dyes using biochar derived from Ulva reticulate is also an effective methodology [23]. Biochar also showed the positive effect in reclamation of salt-effected and acidic [26].

Contrarily, it was shown that biochar, due to its non-cohesive nature, increases soil erosion at the initial stage of mixing of it with soil [14]. When biochar and soil were first mixed together, there was a reduction in soil aggregation. However, it was shown that using biochar along with any cohesive material can reduce such problems and maximize its benefits for agricultural productivity [14].

2.2 Gypsum and lime

For the rehabilitation of alkaline soils, gypsum, with the chemical formula $CaSO_4$.2H2O, is a well-known inorganic soil additive. Gypsum can be used to bind the soil particles on the surface [12]. Gypsum is primarily a calcium supplier for the soil, hence it has a variety of specialized agronomic purposes. Gypsum lowers soil pH and enhances its physico-chemical characteristics. Gypsum also lessens soil erosion, runoff, and significant nutrient and carbon losses. Gypsum's impact on accelerating biomass growth, however, was determined to be minimal. Another inorganic soil amendment with the chemical formula $Ca(OH)_2$ called lime is typically applied in agricultural fields to increase the pH and decrease acidity of the soil. The effects of acids from nitrogen fertiliser, slurry, and heavy rains are neutralized by lime. The addition of lime also improves soil structure, increases earthworm activity, and makes grass more appealing to livestock.

2.3 Anionic polyacrylamide

Anionic polyacrylamide (PAM) can be produced as a cross-linked polymer or as a straightforward linear-chain structure ($-CH_2CHCONH_2-$). PAM is thought to be an effective soil conditioner that should be used in disturbed soils to lessen severe erosion. PAM improves soil cohesiveness while lowering runoff and erosion [8, 9]. According to reports, PAM lessens soil sealing and speeds up soil infiltration [12, 15]. Additionally, it has no impact on the growth of plants or the breakdown of organic waste. No study has yet identified a harmful impact of soil-based anionic PAM. In order to improve soil aggregation in the fields, the PAM is a cohesive material and innovative soil additions. High soil aggregation reduces nutrient loss and soil erosion while boosting soil productivity.

By using PAM correctly in the soil, its efficiency can be increased. The benefits of applying PAM in liquid form to saturated soil are greater (Fig.1). PAM in powder form is useful for sanitizing bodies of water. A typical procedure is to prepare and apply a 0.50% PAM solution in water to the field [11]. On a slope, the liquid PAM mixture should be uniformly sprayed over the soil to thoroughly saturate it before runoff starts. PAM should not be given in its entirety all at once; rather, it should be given gradually over several systematic replications. The acceptable range for anionic charge density is 2 to 30%. For the optimal soil stability effects, according to USDA/ARS, PAM should be strongly anionic, or have more than 20% hydrolysis, and have a molecular mass between 12 and 15 mg/mole. PAM does not work any better at larger doses, according to several researchers, thus it should be administered at the recommended dose. A range of PAM from 20 to 50 kg/ha is highly recommended in the soil to minimize runoff, soil erosion, nutrient loss, and to increase soil productivity [8, 9, 10, 11, 12, 16, 17].

Fig. 1 Surface applications of anionic polyacrylamide solution

To stop nutrient losses and soil erosion, PAM was recommended in a lot of publications. PAM has been recommended by Inbar et al. [16] to prevent runoff and soil erosion in post-fire soils at rates of 25 kg/ha and 50 kg/ha. PAM was utilised by Li and Wang [18] to lessen nutrient loss on steep slopes. A study conducted by Sadeghi et al. [9] to ascertain the quantitative effects of PAM on runoff and soil erosion came to the conclusion that the application rate of 20 kg/ha of PAM is extremely advantageous and advised to reduce runoff and soil erosion. PAM is a helpful supplement to reduce nitrogen and phosphorus losses by minimising soil erosion, according to Chen et al. [19]. According to Xu et al. [20], PAM with humic acid has a favorable effect on soil chemical characteristics and plant metrics.

3. Effect of blending of amendments with anionic polyacrylamide

According to earlier studies, addressing soil-related issues with a single amendment did not result in a long-lasting remedy [14, 9]. For the purpose of understanding how PAM and other soil additions, such as biochar with PAM, gypsum with PAM, and lime with PAM, etc. blend to boost agricultural productivity, very few research have examined the combined effects of these soil amendments. When biochar is incorporated into the soil using the PAM, it begins to stabilize in the soil more quickly and exhibits less of its initial characteristic of accelerating soil erosion. To bond the biochar into the field, PAM acts as a cohesive substance. PAM also aids in lowering the amount of biochar that is lost through runoff after application to the ground. It was discovered that adding PAM to biochar raises the soil's plastic and liquid limits and improves slope stability [11].

Additionally, it was shown that using biochar with PAM can increase crop yield and growth while greatly lowering soil erosion, nitrogen loss, and runoff (Table 1). An enhanced breakdown of anionic PAM is shown when biochar is present. PAM and biochar together promote the breakdown of crop leftovers [21]. According to Wang et al. [22], the addition of PAM boosts soil cohesiveness and lessens the detrimental effects of biochar on soil cohesion. According to Wang et al. [22], using PAM and biochar together could help stabilize slopes and prevent soil erosion. Using biochar and PAM in the soil in full quantities of 800 and 2 g/m^2, respectively, Sadeghi et al. [17] demonstrated that PAM increased inter-rill erosion but decreased sediment concentration. On the other side, biochar significantly reduced runoff and soil erosion. When biochar and PAM were applied together, the outcomes for runoff and soil erosion were better than when they were applied separately.

Table 1 Effect of single and blending applications of soil amendments

S. No.	Soil amendment	% change* in sediment yield/biomass	Reference
1.	Gypsum (2.5 t/ha)	-10.61% in sediment yield, +0.96% in biomass growth	[11]
2.	Gypsum (2.5 t/ha) + PAM (20 kg/ha)	-26.43% in sediment yield, +9.37% in biomass growth	[11]
3.	Gypsum (4 t/ha)	-17.00% in sediment yield	[8]
4.	Gypsum (4 t/ha) + PAM (40 kg/ha)	-25.00% in sediment yield	[8]
5.	Gypsum (5.0 t/ha)	-68.70% in sediment yield, +2.46% in biomass growth	[11]
6.	Gypsum (5.0 t/ha) + PAM (40 kg/ha)	-77.25% in sediment yield,	[11]

		+25.49% in biomass growth	
7.	Biochar (8 t/ha)	-16.24% in sediment yield, +24.87% in biomass growth	[11]
8.	Biochar (8 t/ha) + PAM (20/kg/h)	-42.43% in sediment yield, +76.98% in biomass growth	[11]
9.	Biochar (15 t/ha)	-71.98% in sediment yield, +149.09% in biomass growth	[11]
10.	Biochar (15 t/ha) + PAM (40 kg/h)	-84.61% in sediment yield, +254.05% in biomass growth	[11]
11.	Lime (2.0 t/ha)	-11.00% in sediment yield	[8]
12.	Lime (2.0 t/ha) + PAM (40 kg/ha)	-46.00% in sediment yield	[8]

Note: "-" sign shows the reduction and "+" sign shows the increment.

Along with this, applying PAM and gypsum together in fields reduces soil pH, electrical conductivity (EC), runoff, soil erosion, and nutrient losses more than doing so separately [12]. Crop productivity rises when gypsum is sprayed with PAM as opposed to when it is applied alone [11] (Table 1). Gypsum and PAM do not directly promote the growth of flora, unlike Biochar, but they do prevent soil erosion and nutrient loss, which in turn promotes the growth of vegetation. According to Kebede et al. [8], the ideal dose of PAM to use in a blended application with gypsum and lime is 4 g/m^2. A blended application of amendments was found to be more beneficial than a single application, and Kebede et al. [8] came to the conclusion that PAM with lime could be a useful choice to prevent soil erosion and boost soil productivity in acidic soil.

4. Conclusions

The efficacy of non-cohesive type soil amendments reduces because of their loss from the soil due to erosive agents. A huge reduction in biochar, gypsum and other amendments was observed on sloped locations. This loss makes the unproductive soil remains the same even after application of soil amendment in the field. PAM is organic, cohesive and binder type soil amendments. The efficiency of non-cohesive type soil amendments on plains and sloping surfaces can be increased by combining them with PAM. PAM alone is useful for reducing soil erosion, runoff, and nutrient loss, but it had little influence on plant growth. After employing soil amendments containing PAM, an increase in biomass growth and a decrease in sediment yield were noted. Overall scenario showed that PAM may be applied to soil successfully when combined with other soil additives such as biochar, gypsum, lime etc. Furthermore, understanding the action of PAM on the physical properties of soil on plains as well as on hills requires additional research.

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