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Effect of Hydraulic Seeding Treatments on of Road Cut Slope

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ABSTRACT

Aims In the present study, effect of different hydro seed binder combinations were evaluated on stability clay soil cut slope of road in the campus of Gorgan University of Agricultural Sciences and Natural Resources, Iran.

Materials & Methods The hydro-seed treatments were classified as A (5L m^{-2} water, 50g m^{-2} *Festuca arundinacea* L., 40g m^{-2} polyacrylamide tackifier, 30g m^{-2} starter fertilizer and 20g m^{-2} super absorbent polymer), B (5L m^{-2} water, 70g m^{-2} *Festuca arundinacea* L., 50g m^{-2} polyacrylamide tackifier, 40g m^{-2} starter fertilizer and 30g m^{-2} super absorbent polymer) and C (5L m^{-2} water, 90g m^{-2} *Festuca arundinacea* L., 60g m^{-2} polyacrylamide tackifier, 50g m^{-2} starter fertilizer and 40g m^{-2} super absorbent polymer). Then mean weight diameter, aggregate stability, liquid limit, friction angle and, soil cohesion indices experiments in wet and dry conditions conducted in three replications for each treatment.

Findings Results showed that the maximum value of MWDwet (0.91mm), MWDdry (5.4mm), aggregate stability (88%), liquid limit (48%), plastic limit (35%), friction angle (44.9 degree) and soil cohesion (13.5kPa) obtained by application of hydro-seed C. Minimum percentage of aggregate destruction (38%) and plastic index (13%) obtained in results of hydro-seed C application.

Conclusion The application of hydraulic seeding treatments improved the structural stability, plastic index and shear strength of the soil. Future research in this subject requires to perform in the field. This study will eventually be used in the implementation section.

Keywords Hydro-seed; Aggregate Size; Plastic Index; Soil Destruction Index; Cohesion

CITATION LINKS

[1] Soil water repellency of the artificial ... [2] Contamination of soils with Cu, Na and ... [3] Effectiveness of three post-fire rehabilitation treatments ... [4] The significance of soils and soil science ... [5] Soil-related sustainable development goals: Four ... [6] Soil-erosion and runoff prevention by plant ... [7] Impact of organic matter, iron oxides, alumina, silica and ... [8] Effects of different backfill soils on artificial soil quality for ... [9] Vegetation and soil nutrient restoration of cut slopes ... [10] Using waste to reduce slope erosion on road ... [11] Erosion and vegetation cover in road slopes hydroseeded with ... [12] Hydroseeding application on degraded slopes in the ... [13] Seeding and fertilization effects on plant cover and community ... [14] Post-fire ... [15] Effectiveness of aerial seeding and straw mulch for reducing post-wildfire ... [16] Three hydro-seeding revegetation techniques for soil erosion control on anthropic ... [17] Effectiveness of cellulose, straw and binding materials for mining spoils revegetation ... [18] Effectiveness of hydromulching to reduce runoff and erosion in a recently burnt pine plantation in ... [19] Effect of area development on the stability ... [20] Effects of surface treatment on surface sealing ... [21] The effects of slash and sawdust on reducing soil ... [22] Trade-off between runoff and sediments from treated ... [23] Sustainable watershed management through applying ... [24] Superabsorbent polymer materials: a ... [25] Standard D2434; Permeability of granular ... [26] Soil quality Indices in pure and mixed forest ... [27] Runoff water quality and vegetative establishment for groundcovers ... [28] Size distribution of ... [29] Aggregate stability and assessment ... [30] Mean weight-diameter of soil aggregates as a statistical ... [31] On the investigation of the physical properties ... [32] Preliminary experiment on shear in soil ... [33] In situ shear tests of soil blocks with ... [34] Revegetation techniques on clay soil slopes in northern ... [35] Impact of soil water repellency on hydrological and erosion ... [36] Effect of hydroseeding on grass yield and water use ... [37] Improvement in the water retention characteristics of ... [38] Superabsorbent polymer properties and concentration effects on water retention under drying ... [39] Aggregate stability as affected by polyacrylamide ...

Introduction

Soil is the main element of the earth and important part of engineering projects [1, 2]. Cut slopes that are created via road construction are susceptible to water erosion and commonly stabilized by revegetation [3]. Mitigation of soil erosion is in lien of the United Nations (UN) adopted the Sustainable Development Goals (SDGs) [4, 5]. Soil stability is the resistance of soil structure against mechanical or physical-chemical destructive forces [5]. Determining soil stability gives information on the sensitivity of soils to water and wind erosion, which might be prevented e.g. by revegetation [6]. There is mounting document showed that vegetation recovery and reconstruction of cut slope should be carried out after road construction to enhance the stability of cut slopes, conserve and control soil erosion [7, 8]. Vegetation on road embankments protects the slopes from soil erosion and its consequent adverse impacts. On the other hand, the soil of new cut slopes in roads is not very fertile [9], this is contribute to reduce soil protection against erosion [10]. Different techniques including hydro-seeding, mulching and fertilization were used with the purpose of vegetation establishment upon cut slops. Techniques hydro-seeding, mulching, and fertilization have been used [11]. Hydro-seeding is a practice that involves spraying a slurry mix made of various components (seed, water, fertilizer, and sometimes fiber mulch) for the soil restoration of road cut slop to increase vegetation cover and reduce erosion [12, 13]. Hydro-seeding improving the soil stability and reducing raindrop impact erosion and runoff during precipitation events by increasing infiltration into the soil, as well as increasing soil water-holding capacity via decreasing soil evaporation [14, 15]. Albaladejo Montoro [16], Brofas *et al.* [17], Jozefaciuk *et al.* [7], Prats *et al.* [18], Sutejo and Gofar [19], Zhang *et al.* [20] worked about using of hydro-seeding to increase soil stability on cut slops. Since vegetation establishment on road cut slop in the first year of road construction is essential in order to increase soil stability and reduce erosion. Therefore, small scale field experiment at an artificial hill was developed off-site to test different hydroseed binder combinations. In this study grass species (*Festuca arundinacea* L.) in form of hydro-seed was used to stabilize the road cut slopes. The objective of the present study was to examine the effect of different hydro-seed binder combinations on soil structural stability indices representing the mechanical properties.

Materials and Methods

Study soil

The study site was located in the campus of Gorgan University of Agricultural Sciences and Natural Resources (36°50´32″ N and 54°26´22″ E) in Golestan Province, Iran (Figure 1). The experiments were conducted in April 2018 on road cut slopes with obvious bare and eroded surfaces. The soil texture of the cut slope was clay (14% sands, 40% silts, 46% clays). Soil bulk density was 1.2g cm^{-3} with a pH of 7.7 [20]. Climate records as measured at a Gorgan Weather Station show that the mean annual air temperature during the study was 18°C.

Soil stability indices

Hydro-seed binder in the present study was produced based on the native materials and hydro-seeding protocol options [21]. Formulation applied to produce hydro-seed binder was as Table 1. Polyacrylamide (PAM) tackifier is a polymer from acrylamide subunits is used to increase the soil structure stability [22, 23]. The use of PAM has been recognized as the best management practice (BMP) by the USDA-Natural Resources Conservation Service (NRCS) [4]. They are derived from plant materials which include natural polysaccharide (ionic starch) and agar. Seed starter fertilizer 20-20-20 formulation (fortified amino acids+gibberellic acid+micro elements) is ideal for hydro-seeding. Moreover, this fertilizer contains nitrogen, phosphorus, potassium (N, P, K) [24]. Super absorbent polymer (SAP) is a water-soluble material with a high absorption capacity. To establish this binder, it is important to prepare the cut slope and remove weeds. Treatments were sprayed on soil cut slopes by hydro-seeder machine at the laboratory test (Figures 2 and 3) [25].

Table 1) Formulation of hydro-seed binder used in the present study

hydro-seed binder combinations	hydro-seed A	hydro-seed B	hydro-seed C
Water (L m^{-2})	5	7	10
***Festuca arundinacea* L.** (g m^{-2})	50	70	90
Polyacrylamide tackifier (g m^{-2})	40	50	60
Starter fertilizer (g m^{-2})	30	40	50
Super absorbent polymer (g m^{-2})	20	30	40

Atterberg limits

After 40 days from the hydro-seeding application, 30 soil samples were taken from 0-10cm depth (Shallow soil instability is often in this depth) of the treated cut slope and then Atterberg limits, shear strength and MWD experiments in wet and dry conditions were conducted in three replications for each treatment. For each replication, 50g of soil sample with aggregates size of <4.75mm was weighed out for sieving. Soil aggregates were transferred to the series of sieve with 2, 1, 0.5, 0.425, 0.212, 0.090, and 0.045mm openings. This machine moves the sieve up and down (for wet sieving: in the water) through a vertical distance of 1.5cm at the rate of 30 oscillations per minute. The remaining soil aggregates on sieve are put into the oven for approximately 24 hours in 105°C [26, 27].

MWD of soil aggregate was calculated using Equation 1:

$$MWD = \sum_{i=1}^{K} W_i \bar{X}_i \quad (1)$$

Where X_i is the mean diameter of remained aggregate on sieve, W_i is the ratio of the weight of remained aggregates on each sieve to total weight of sample and K is the number of sieves. After the wet sieving method, the Aggregate Stability (AS) index was calculated using Equation 2 [28]:

$$AS = \frac{WSA - MG}{MS - MG} \times 100 \quad (2)$$

Where WSA is the weight of remained aggregates on sieve 0.25mm. MG is the weight of gravel and MS is the total weight of sample. The percentage of aggregate destruction is another index for evaluating physical structure of soil which is obtained from the measuring of MWD of soil aggregate in wet and dry conditions. To determine the destruction index (DI), the weight of aggregates greater than 0.25mm is calculated in dry (MD) and wet (MW) conditions [29] using Equation 3:

$$DI = \frac{MD - MW}{MD} \times 100 \quad (3)$$

In Atterberg limits analysis, liquid limit (LL) was determined using Equation 4 [30]:

$$LL = W_N * \left[\frac{N}{25}\right]^{0.121} \quad (4)$$

Where N is the number of drops of the cup required to close the groove, W is the soil moisture content (%) that the groove is closed. Moisture content was determined using Equation 5:

$$W = \frac{W_1 - W_2}{W_2 - W_3} \times 100 \quad (5)$$

Where W_1 is the weight of the can (g)+wet soil (g), W_2 is the weight of the can (g)+dry soil (g) and W_3 is the weight of the empty can (g). The tested samples of the soils were oven-dried at 105°C for 24 hours.

PL is the moisture content at which the soil sample is cracked during kneading (Equation 5). The Plastic Index (PI) of a soil is the numerical difference between its LL and its PL (Equation 6) [31]:

$$PI = LL - PL \quad (6)$$

Shear strength

The shear parameters of soil were measured according to the standard DIN 18137 (German standard agency for shear strength parameters and is the abbreviation of Deutsches Institut für Normung) by means of the grain size fraction <0.5mm using a box shear apparatus. After consolidating each sample for a minimum of 150 minutes, normal stresses of 10, 20, 40, and 80kPa were incrementally applied to obtain the shear strength, the angle of internal friction Φ, and the cohesion *C* (Equation 7) [32].

$$SS = C + \sigma tan\,\Phi \quad (7)$$

Where SS is the shear strength, C is the cohesion, σ is the normal stress on the failure plane and Φ is the angle of internal friction. The friction angle can be determined as Equation 8. Besides the cohesion of soil was calculated using Equation 9 [33].

$$\Phi = tan^{-1}\left(\frac{SS}{\sigma}\right) \quad (8)$$

$$\mathrm{C} = \frac{\sigma_1 - \sigma_3 tan^2(45 + \frac{\Phi}{2})}{2\tan(45 + \frac{\Phi}{2})} \quad (9)$$

σ_1 is the major principal effective stress at failure and σ_3 is the minor principal effective stress at failure.

Statistical analysis

In the present study, since the number of replications among treatments was not same because of the removal of unsuitable data, therefore the soil stability and plasticity indices were statistically analyzed using General Linear Model (GLM) procedure in SAS 9.4 M3 software. SNK test (Student-Newman-Keuls) was used to compare means among different treatments.

Findings

Hydro-seeding treatments

The results showed that the application of hydraulic seeding treatments had a significant effect on structural stability indicators. The addition of a hydroseed binder to the soil increased the MWDwet, MWDdry and AS and decreased the DI, significantly (Table 2). The maximum value of MWDwet, MWDdry and AS was obtained by application of hydro-seeding C and via increasing the concentration of materials MWDwet, MWDdry and AS. The minimum percentage of aggregate destruction (DI) was obtained by application of hydro-seed C and regard to DI, there was no significant difference between the different combinations of hydro-seed binders (Table 3).

Atterberg limits

The findings showed that application of hydro-seed treatments had a significant effect on Atterberg limits and the addition of hydro-seed binder to the soil increased LL and PL and decreased PI, significantly (Table 4). The maximum value of LL and PL was obtained by application of hydro-seed C and by increasing the concentration of materials the LL and PL increased. The minimum PI was obtained by application of hydro-seed C and regard to PI, there was no significant difference between the hydro-seed treatment A and control (Table 5).

Shear strength

In the present study, root structure of the *Festuca arundinacea* L. has strengthened the soil and keeping soil aggregates on its place. Application of hydro-seed treatments had a significant effect on soil shear strength and addition of hydro-seed binder to the soil increased friction angle and soil cohesion, significantly (Table 6). The maximum value of friction angle and soil cohesion was obtained by application of hydro-seed C and by increasing the concentration of materials, the friction angle and soil cohesion increased (Table 7).

Increasing SAP concentration from 20 to 40g m^{-2} significantly increased the soil aggregate stability and reduced its plasticity index relative to the control, but led to a remarkable increase in soil cohesion and mean weight diameter, and enhanced friction angle. These relationships were also observed for PAM and N, P, K. Indeed, MDW condition, aggregate stability and soil cohesion increased as the PAM and N, P, K in hydro-seed combination increased. There was a significant relationship between the concentrations of PAM in hydro-seed binder and the as regression equation, which was indicated by the greatest concentration of PAM, the lowest values of DI can be detected. This relationship was also confirmed between the PAM and PI (Diagram 1).

Table 2) Analysis of variance for soil structural stability indicators

Sources of variations	df	Mean squares			
		MWDwet	MWDdry	AS	DI
Treatment	3	0.035**	0.223**	342.563*	241.112ns
Error	8	0.001	0.012	12.512	9.856
CV (%)		5.124	7.635	4.524	6.131

df: degree of freedom; MWDwet: Mean weight diameter of aggregates in wet sieving; MWDdry: Mean weight diameter of aggregates in dry sieving; AS: aggregate stability; DI: Destruction index; **, *Significant at probability level of 1% and 5%, respectively; ns: no significant

Table 3) Effects of hydro-seed treatments on soil structural stability indicators

Variables	Control	Hydro-seed A	Hydro-seed B	Hydro-seed C
MWDwet (mm)	$0.56^{d}\pm0.02$	$0.78^{c}\pm0.08$	$0.85^{b}\pm0.09$	$0.91^{a}\pm0.09$
MWDdry (mm)	$4.0^{c}\pm0.7$	$4.4^{b}\pm0.9$	$4.8^{ab}\pm0.9$	$5.4^{a}\pm0.8$
AS (%)	$55^{c}\pm15$	$73^{b}\pm14$	$84^{a}\pm18$	$88^{a}\pm15$
DI (%)	$64^{a}\pm8$	$45^{b}\pm6$	$42^{b}\pm5$	$38^{b}\pm4$

Different superscripts in a row show the significant difference at a probability level of 5% based on the SNK test.

Table 4) Analysis of variance (ANOVA) for soil Atterberg limits

Sources of variations	df	Mean squares		
		LL	PL	PI
Treatment	3	8.47	8.71	9.20
Error	8	1.05	0.91	1.20
CV (%)		3.245	5.421	4.785

LL: Liquid limit; PL: Plastic limit; PI: Plastic index

Table 5) Effects of hydro-seed treatments on soil Atterberg limits

Variables	Control	Hydro-seed A	Hydro-seed B	Hydro-seed C
LL (%)	44.0^{b}±5.1	45.2^{b}±5.8	45.5^{b}±3.1	48.0^{a}±3.5
PL (%)	22.0^{c}±2.9	24.1^{c}±1.6	29.0^{b}±4.1	35.0^{a}±2.1
PI (%)	22.0^{a}±3.2	21.1^{a}±1.8	16.5^{b}±2.1	13.0^{c}±2.7

Different superscripts in a row show the significant difference at a probability level of 5% based on the SNK test.

Table 6) Analysis of variance for soil shear strength

Sources of variations	df	Mean squares	
		Φ	C
Treatment	3	13.22	18.67
Error	8	1.01	1.02
CV (%)		8.421	7.254

Φ: Internal friction angle; C: Cohesion

Table 7) Effects of hydro-seed treatments on soil shear strength

Variables	Hydro-seed A	Hydro-seed B	Hydro-seed C
***Φ* (degree)**	41.8^{b}±4.7	44.4^{a}±5.2	44.9^{a}±5.5
C (kPa)	9.5^{b}±1.1	10.1^{b}±1.8	13.5^{a}±2.0

Different superscripts in a row show the significant difference at a probability level of 5% based on the SNK test.

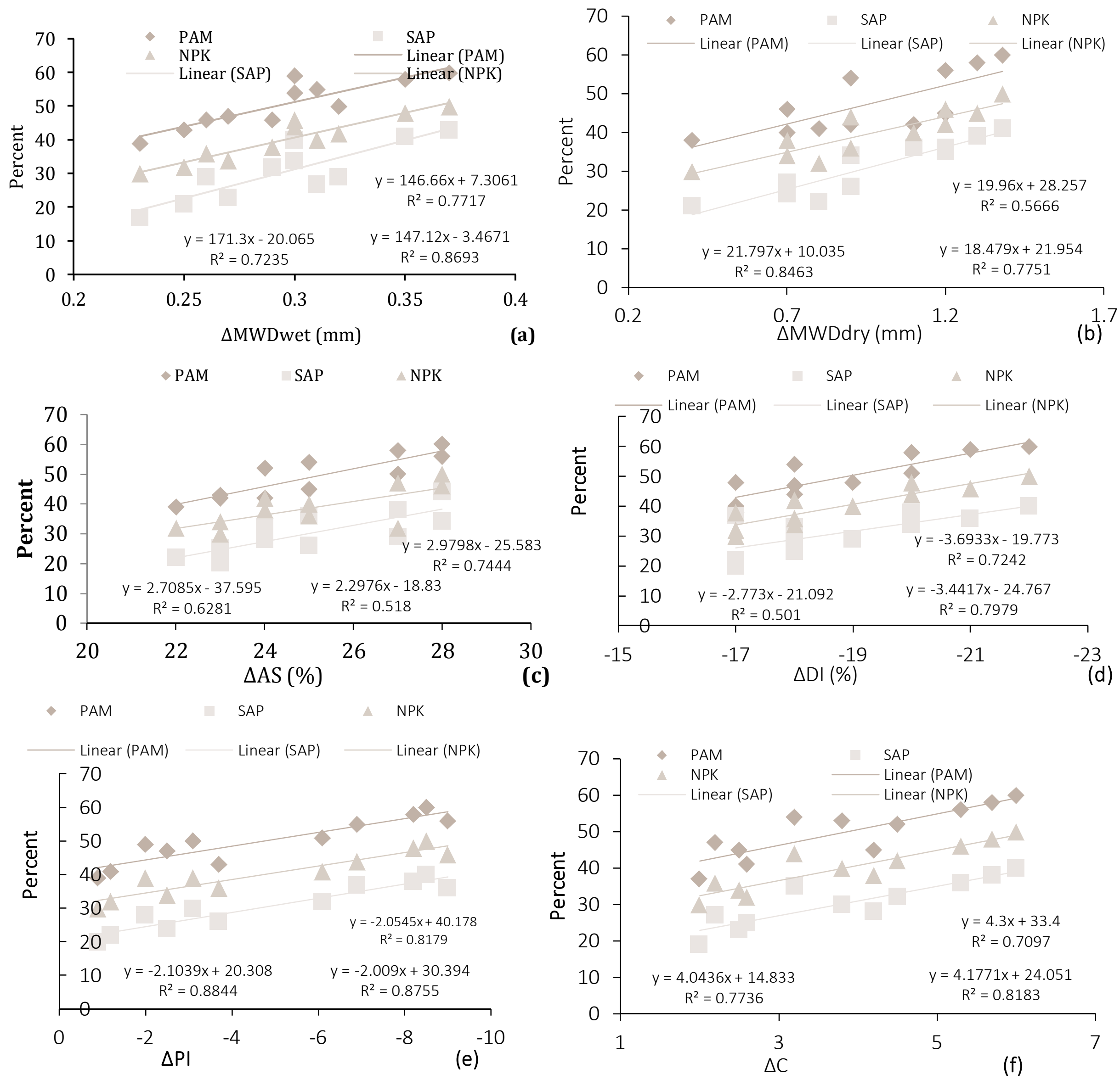

Diagram 1) Relationship between hydro-seed materials (PAM, SAP, and N, P, K) and soil structural stability

Discussion

Hydro-seeding can achieve grown grass cover in the short term by stabilizing the soil [34]. Selection of a proper seed mix is important for roadside revegetation. Grass rapidly develops a fine, extensive root system that stabilizes soil particles [35, 9]. Superabsorbent polymer (SAP) materials are hydrophilic networks that can absorb and retain huge amounts of water or fertilizer solutions in hydro-seed texture. The water and fertilizer gradually absorbed by root system and *Festuca arundinacea* L. can use these materials especially in hard conditions [36, 9]. In the present study, hydro-seed binder increased the soil MWDwet, MWDdry and AS and decreased DI. Shahid *et al.* [37] and Yu *et al.* [38] reported that synthesized polymer in hydro-seed binder increased soil aggregate stability and led to a remarkable increase in soil MWD. There wasn't a significant difference between the hydro-seed B and hydro-seed C in terms of AS, because most of the PAM added to the soil was adsorbed on the exterior surfaces of the aggregates. Higher amount of PAM in treatments of hydro-seed B and C had no significant impact on aggregate stability [37]. Moreover, in the present study it was detected that the addition of hydro-seed binder to the soil increased LL and PL and decreased PI. The presence of PAM in hydro-seed combinations increases the viscosity of the soil and leads to a reduction in soil loss [18].

Increasing SAP concentration from 20 to 40g m^{-2} significantly increased soil aggregate stability and reduced its plasticity index relative to the control, as well as led to a remarkable increase in soil cohesion MDW and friction angle. This result was in agreement with the findings of Shahid *et al*. [37] and Yu *et al*. [38]. They showed that soil treated with SAP significantly enhanced soil water holding compared with the controls. Furthermore, the seed germination rate was significantly higher in polymer-treated soils than in the controls [39]. Besides, the findings of the present study proved the positive relationship between the PAM concentration and shear strength. The positive effects of PAM on shear strength of soil are related to preserving and increasing soil aggregation and water infiltration. Tackifier binds the SAP and seed to create a continuous and resistant cover to protect the soil against instability.

Conclusion

According to the results of this study, the application of hydraulic seeding treatments improved structural stability, plastic index and shear strength of soil. From the management point of view, results support the use of hydro-seed C as an efficient bioengineering alternative to stabilize cut slopes after road construction. The success of hydraulic seeding depends on substrate characteristics and climatic conditions in the study area. In general, hydraulic seeding with lower fertilizer, super absorbent, and tackifier was more sensitive to site conditions and hydraulic treatment and sometimes failed completely. Some components such as fertilizer should be omitted in fertile soil and greater emphasis be placed on the tackifier and plant species.

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