Effect of Hydromulch Binders on Reduction of Embankment-Induced Soil Erosion and Sediment Concentration

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ABSTRACT

Aims Hydromulching treatments are increasingly being used as a feasible alternative of landscape management for runoff and soil erosion control after road construction. Towards this, the present study aimed at evaluating the effect of hydromulch binders on reduction of embankment-induced soil erosion and sediment concentration.
Materials & Methods This experimental study was conducted in Golestan Province, Iran in March 2017. Two types of soil stabilizers were used. Hydromulch A included water absorbent, Festuca arundinacea L. seed, tackifier, fertilizer, and bio humus. Hydromulch B was combined from hydromulch A, cellulose fiber, and natural yarn. Then, the hydromulches as well as the non-hydromulch traditional mix (seed and animal fertilizer) were separately sprayed on artificial bare slopes. Treated soil were translocated and established in the specific boxes for measuring grass biomass, sediment concentration, runoff, and soil erosion under the rainfall simulation. The data were analyzed by one-way ANOVA and Duncan multiple comparison tests.
Findings Hydromulch A and traditional mix produced lower value of the total biomass of grass compared with hydromulch B. Hydromulch B yielded significantly less runoff volumes than the other treatments. Only the hydromulch B significantly reduced soil erosion compared with that of the hydromulch A and traditional mix ($p<0.05$).
Conclusion Hydromulch B is clearly much more efficient than hydromulch A and traditional seeding in terms of minimizing soil erosion. Traditional mix seeding is not able to promote an effective grass cover to reduce soil erosion from artificial slopes. Hydromulch B provide favorable moisture and soil temperatures for grass seeds and this accelerates plant establishment.

Keywords Disturbed Slope; Land Management; Sediment Yield; Soil Amendment; Soil Conservation

CITATION LINKS

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Introduction

Seeding is the distribution of seeds for vegetation establishing at a desired density and species composition to minimize the soil erosion [1, 2]. This traditional soil stabilization method has been improved. Recently, groundcovers such as grasses are usually applied on soil slopes by hydromulching [3].

Hydromulching is an important and popular treatment to stabilize steep slopes [4]. It is well documented that the hydromulch binder decreased the sediment concentration by providing cover on bare soil, reduced the raindrop impact erosion, and decreased the runoff during precipitation events by increasing infiltration into the soil and soil water-holding capacity via soil evaporation decreasing [5-8].

Created artificial slopes during the topographic change resulted from road construction are susceptible to water erosion and commonly stabilized by revegetation [3]. Water erosion is the most damaging type of erosion, especially in new constructing projects [9]. In results of water erosion, the soil particles are separated and transported by water.

The slope angle, compaction, and erosion potential of the new slopes hinder the natural rapid establishment of vegetation cover, which makes it necessary to apply erosion control treatments [10, 11]. Effective road slope stabilization methods such as hydromulching have been developed and used around the world.

Over the past decade, the use of hydromulched grasses has greatly increased because of their restoration and habitat advantages, as well as their beauty [12, 13]. Some grasses can reduce runoff and sediment concentrations by 65% to 70% and 80% to 95%, respectively [14]. Their cover also consists of numerous grass stems that enhance the trap sediment and slow down surface runoff.

Grasses are also capable of forming root mats in the soil that act as mechanical barriers to soil erosion [15, 16]. Successful grass establishment requires a detailed analysis of the study site in terms of access to irrigation water, established weeds, and other ground covers as well as soil erosion process [17, 18].

Hydromulching is a process, by which seed, water, fertilizer, and sometimes fiber mulch and binders are blended together in a tank and applied onto bare soil surfaces through hydromulcher machine [10, 7]. Cellulose fibers, fertilizer, and the grass seed in mulch can produce absorbent layer when sprayed on the soil.

Due to this layer creation, the runoff and water erosion are consequently reduced and the seed germination is accelerated [8, 19, 20]. Findings showed that bacteria-based fertilizing agent, biostimulant, and a mixture of components increased the germination percentage [21]. Nowadays, the use of hydromulching is encouraged for the restoration of forest road embankments, but their success is unknown for Hyrcanian forest of Iran. Several biotic and abiotic constraints have been reported that partially explain the failure of this method in Mediterranean Region [21]. However, information regarding the effectiveness of these techniques in erosion control and grass biomass yield components is scarce.

In this study, grass species of *Festuca arundinacea* L. was used to establish the steep slopes. The aim of this study was to evaluate the effect of hydromulch binders on reduction of embankment-induced soil erosion and sediment concentration.

Materials and Methods

Study area description: The experiments of the present experimental research were conducted in the forest engineering laboratory at the Gorgan University of Agricultural Sciences and Natural Resources (36˚50´32˝ N and 54˚26´22˝ E) in Golestan Province, Iran in March 2017 on artificial soil slopes with obvious bare and eroded surfaces. These soil slopes were created when developing roads in university campus. Climate records as measured at a Gorgan Weather Station showed that the mean annual air temperature was 32°C, with a maximum daily temperature of 39°C for the hottest day, and a daily minimum temperature of 27°C for the coldest day. The mean annual rainfall was 562mm. The soil texture was clay (14% sands, 40% silts, 46% clays). Soil bulk density was 1.2g cm^{-3} with a pH of 7.7.

Hydromulch production and application: Hydromulch binders in the study were produced based on the native materials and hydromulching international protocol options [16, 1, 5] (Table 1). To establish these binders, it is important to clear the soil slopes and remove weeds to ensure maximum contact of the hydromulch slurry to the soil.

Table 1) Protocol of hydromulch combinations used in soil erosion control experiments [16, 1, 5]

Mixes	Hydromulch A	Hydromulch B	Traditional mix
Water (l)	5	5	5
Seed (g)	30	30	30
Organic tackifier (g)	20	20	0
Starter fertilizer (g)	30	30	0
Bio Humus (g)	0	30	0
Cellulose fiber mulch (g)	0	100	0
Super absorbent (g)	10	10	0
Natural yarn (g)	0	10	0
Animal fertilizer (g)	0	0	30

Grass seeds of *Festuca arundinacea* are enclosed by sets of bracts, called the lemma and palea. These structures provide a protective covering and are believed to reduce seed breakage during seeding agitation and application [16]. *Festuca arundinacea* was selected for the study because it is a *perennial* grass species native to Hyrcanian forest of Iran. Organic tackifiers are sticking agents that bind soil particles together and protect the surface from wind and water erosion [1]. They are derived from plant materials, which include natural polysaccharide (ionic starch) and agar [5].

Fortified amino acids + Gibberellic acid + Micro elements is ideal for hydromulching [1]. Adding fertilizer to the slurry can reduce germination due to the effects of salts on seed imbibitions, especially in sites with low rainfall. Cellulose fiber mulch (saw dust) together with the bio-humus will act as an absorbent mat, holding enough moisture to allow proper germination of the grass seeds [10]. Natural yarn will hold materials together as a sheet and is referred to as a bonded matrix. The length of the yarn is an important characteristic in creating a matrix sheet. The length of goat yarn in the study was 2cm due to the mechanical limitations of hydromulcher machine. The forms of seeding in the current research was broadcast seeding, which is casting grass seeds (*Festuca arundinacea*) on the surface of soil [16]. Seed that is sown on the surface and pressed into the soil increases germination rates over broadcast sowing. Seeds are dropped from a seeder mounted in front of the imprinter and, then, pressed into the soil. A general view of the study treatments were shown (Figure 1).

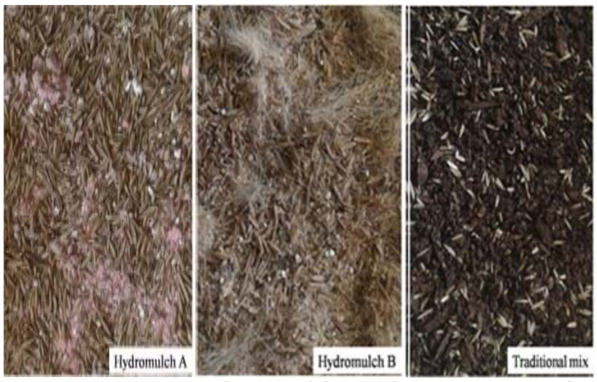

Figure 1) A general view of the study erosion control treatments

Experimental design: The erosion control treatments examined in the present study were hydromulch A, hydromulch B, and traditional mix. Indeed, non-hydromulch traditional treatment was considered as control. Treatments were conducted on artificial soil slopes by hydromulcher machine (Figure 2).

Figure 2) General view of hydromulching operation in campus of Gorgan University

Then, soil samples were translocated to the boxes in 5 replications for rainfall simulation analysis. The study soil box had variable slopes of 20, 45, and 70 degree with dimensions of 0.40m length, 0.2m depth, and 0.25m width. The bottom of the soil box was filled with 10cm sand covered with a layer of gauze to keep the water drainage conditions close to those of the test soil; thus, water can easily infiltrate into the soil during the test [5]. Most grasses germinate in 5 to 10 days at optimal temperatures.

The experimental design consisted of randomized blocks arranged in a 3 (treatments) × 3 (slopes) factorial with 5 replications.

Totally, 45 soil boxes were used in the study. The shelf-life of this method was 1 month. Hydromulching should be renewed on an annual basis. Mean daily irrigation was 350ml for each $0.1m^2$. The cost of hydromulching was 2.5 dollars per square meter.

Runoff and soil erosion measurements: After 40 days from treatment time, each of the soil boxes was treated with the rainfall of a portable single nozzle simulator for 10 minutes [9]. The drop size was 3mm. Rainfall intensity of 50mm h^{-1} with the temperature of 23±3°C was falling from the Schlick r18650 nozzle at 3m above the soil boxes with an area of $0.1m^2$. Runoff and sediment were collected by a gauge and, then, runoff volume, runoff coefficient, sediment concentration, and soil erosion were measured for each box. Sediment was oven-dried at 105°C for 2 hours at least [5]. The runoff coefficient was calculated based on the following formula [13, 18]:

$$RC = \frac{RH}{PH} \times 100$$

RC, RH, and PH were the runoff coefficient (%), runoff height (mm), and rainfall height (mm), respectively [17, 18].

Biomass measurements: Experiment was concluded after 40 days and various growth indices such as root and stem length, stem fresh weight, root fresh weight, stem dry weight, and root dry weight were measured [21-25]. Dry weight was determined after drying the grass seedlings in an oven at 80°C for 24 hours. Then, seedlings weight was measured by digital balance with accuracy of mg [25].

Statistical analysis: Statistical analyses were conducted, using SPSS 25.0 (SPSS Inc., Chicago, USA). To test whether the differences among the treatments were statistically significant ($p<0.05$), one-way analysis of variance (ANOVA) and the Duncan multiple comparison tests were used.

Findings

Analysis of variance: There was a statistical difference among soil erosion control treatments for the water erosion variables, as the hydromulch B produced lower sediment and runoff than the other two treatments especially in 20° plots.

Biomass production of grass: The grass biomass provided by the traditional mix was very low in all replications. Treatment had a significant effect on total dry weight (TDW) of grass, with higher values in the hydromulch B than in the other two treatments. At this time, total length (TL) of grass was 11.5cm and 15.7cm in the plots of hydromulch A and B, and 8.7cm in the traditional mix plots, respectively. Vitality ranged from 73.8% to 74.4% in hydromulch B (Table 2).

Runoff volume and soil erosion: Hydromulch B significantly generated less sediment and runoff volume than the other treatments (Diagram 1. a, b). Soil erosion was minimal in the slope of 20°C in hydromulch B (Diagram 2. a, b, c). Immediately after treatment application, the mean soil covered by hydromulch B was recorded approximately 70%. The mean amount of soil erosion from all plots during the rainfall simulation in the hydromulch B was 121.19g m^{-2}, whereas in the hydromulch A and traditional mix, the corresponding amounts were 152.43 and 214.54g m^{-2}, respectively (Table 3).

Table 2) Effect of the different treatments on mean of grass biomass

Slope (%)	Leaf Length (cm)	Root Length (cm)	Total Length (cm)	Leaf Fresh Weight (gm^{-2})	Leaf Dry Weight (gm^{-2})	Root Fresh Weight (g)	Root Dry Weight (gm^{-2})	Total Fresh Weight (gm^2)	Total Dry Weight (gm^{-2})
20									
A	7.0±0.9^b	6.0±0.9^b	13.0±2.1^b	66.4+7.0^b	16.0±3.1^b	42.6±5.7^b	19.9±2.4^a	109.0±12.7^b	35.9±5.5^a
B	10.0±0.1^a	7.5±0.5^a	17.5±0.3^a	87.7±9.6^a	20.5±2.4^a	56.9±7.6^a	16.4±1.3^b	144.6±17.2^a	36.9±3.7^a
Traditional	6.0±0.2^b	2.7±0.4^c	8.7±0.4^c	15.5±1.2^c	7.1±0.9^c	9.9±1.1^c	6.9±0.6^c	25.5±2.2^c	13.9±1.5^b
45									
A	6.5±0.9^b	5.0±0.8^b	11.5±1.3^b	49.7±4.9^b	17.9±2.6^a	13.5±1.8^b	8.5±0.9^b	63.2±6.6^b	26.4±3.5^a
B	8.5±1.0^a	7.2±1.5^a	15.7±1.5^a	54.2±8.5^a	12.2±1.0^b	34.2±2.6^a	11.7±1.4^a	88.4±11.0^a	23.8±2.4^a
Traditional	6.0±0.2^b	2.7±0.1^c	8.7±0.4^c	8.3±0.8^c	4.4±0.2^c	6.2±0.9^c	4.9±0.1^c	14.5±1.5^c	9.2±0.3^b
70									
A	6.5±0.6^a	4.0±0.7^b	10.5±1.2^b	22.3±3.9^b	7.65±0.90^b	17.7±2.3^b	8.3±0.8^b	39.9±6.2^b	15.9±1.6^b
B	7.5±0.5^a	6.2±1.4^a	13.7±1.2^a	52.7±5.6^a	11.3±1.1^a	33.6±4.6^a	11.3±1.6^a	86.3±10.2^a	22.6±2.7^a
Traditional	5.5±0.3^a	2.5±0.3^c	8.0±0.4^c	4.1±0.5^c	2.3±0.1^c	2.7±0.1^c	1.1±0.1^c	6.8±0.5^c	3.4±0.2^c

Means followed by different lower-case letters within columns are significantly different ($p<0.05$)

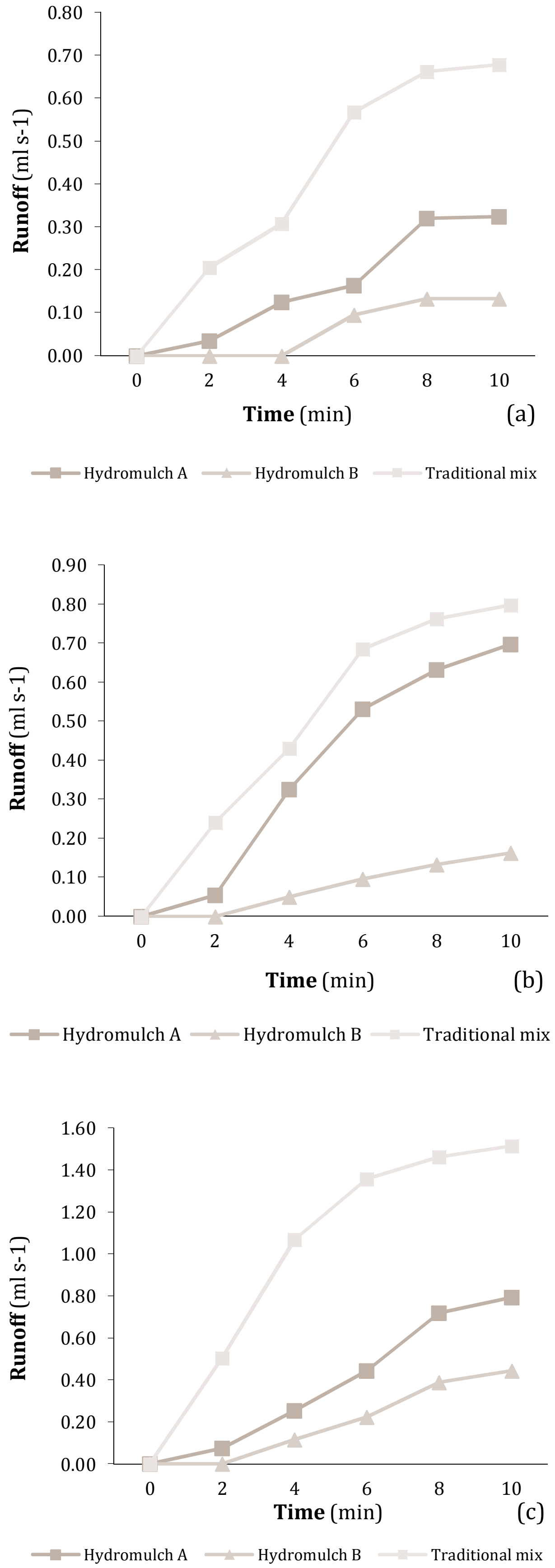

Diagram 1) Behavior of runoff treated with hydromulch binders in different slopes (a) 20°, (b) 45°, and (c) 70°

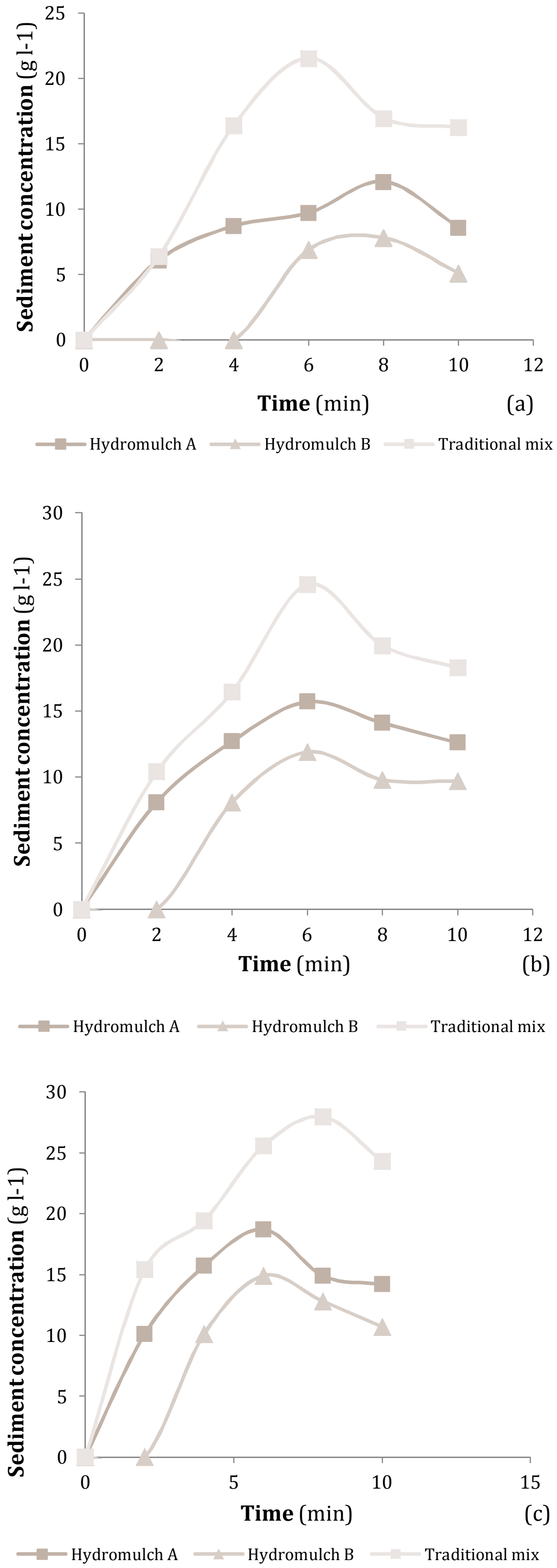

Diagram 2) Sediment yield from plots treated with hydromulch binders in different slopes (a) 20°, (b) 45°, and (c) 70°

Table 3) Effect of treatments on runoff and erosion parameters

Slope (%)	**Biomass** (g m^{-2})	**Runoff volume** (ml)	**Runoff coefficient** (%)	**Sediment concentration** (g l^{-1})	**Soil erosion** (g m^{-2})
20					
Hydromulch A	35.9^{a}±5.8	840^{b}±74	33.60^{b}±4.1	12.30^{a}±2.9	89.82^{b}±9.1
Hydromulch B	36.9^{a}±8.4	730^{c}±45	29.20^{c}±5.2	3.75^{b}±0.5	41.64^{c}±5.5
Traditional mix	13.9^{b}±3.8	990^{a}±96	39.60^{a}±8.6	11.88^{a}±0.9	97.46^{a}±8.8
45					
Hydromulch A	26.4^{a}±4.5	900^{b}±87	36.00^{b}±5.5	15.69^{b}±1.2	155.32^{b}±35.1
Hydromulch B	23.8^{a}±4.8	820^{c}±59	32.80^{c}±6.4	15.12^{b}±2.3	133.10^{c}±44.5
Traditional mix	9.2^{b}±1.1	1090^{a}±89	43.60^{a}±6.1	20.07^{a}±3.3	168.60^{a}±74.2
70					
Hydromulch A	15.9^{b}±3.2	910^{b}±85	36.40^{b}±5.9	23.31^{b}±4.1	212.14^{b}±65.5
Hydromulch B	22.6^{a}±4.7	880^{b}±65	35.20^{b}±7.4	20.98^{c}±3.8	188.83^{c}±48.7
Traditional mix	3.4^{c}±0.4	1110^{a}±88	44.40^{a}±8.2	28.01^{a}±4.0	305.31^{a}±36.8

Means followed by different lower-case letters within columns are significantly different ($p<0.05$)

Discussion

Root length and biomass in plots treated by hydromulch B were significantly more than that of other treatments due to the large water holding in cellulose fiber and super absorbent and microbial activity in bio-humus component of hydromulch B [26, 27]. Grass and legume cover can mitigate soil erosion problems. Foliage protects the soil surface and reduces the impact of runoff [7, 28]. In the present study, runoff volume and coefficient in response to the hydromulch treatments were significantly lower than that of response to the traditional mix type. The reason of this case was that the surface of grass seeds in traditional mix had not been covered by soft layer of organic fertilizer immediately after seeding [3, 16, 29]. Moreover, numerous long grass roots growing almost vertically downwards are able to penetrate and mitigate the soil erosion [26]. Grass root in soil increased the compressive and shear strength [27]. This finding was in agreement with the findings of Gyasi-Agyei [15], Fox *et al.* [16], and Li *et al.* [14] and in disagreement with the findings of Gobinath *et al.* They reported that the permeability of the soil was generally reduced by the application of the grass root. Consequently, grass root is a low cost material that can be effectively used to improve the stability of soils by reducing their sedimentation and permeability [27].

Hydromulch treatments successfully reduced sediment during rainfall simulation. Hydromulch provided most of the organic content and grass cover during the study and it was the reason for erosion reduction. Soil should be tested prior to seed planting to ensure proper levels of organic content [13, 30]. Additional organic content may be needed to improve soil structure, nutrients supply, and promote vegetation establishment [31]. The large sediment amounts measured on the traditional mix plots were probably due to the low percentage grass biomass. Enriquez *et al.* applied hydromulch at 3500kg ha^{-1} consisted of a mixture of organic fibers, water, and seed to reduce runoff and erosion in central Portugal. They concluded that hydromulch reduced runoff volume by 70% and soil erosion by 83% compared to bare soil tested the effectiveness of hydromulching techniques with the application of vegetal mulch, hydromulching with added humic acid, hydroseeding with vegetal mulch and added humic acid and a control without hydromulching or soil amendment. They found that all the hydromulching treatments significantly reduced runoff and soil erosion [11, 12]. This was consistent with the findings of this study. We detected that soil loss in plots treated by hydromulch B was less than other treatments. Mulch is most important for curbing first-year soil erosion. Excelsior, straw, and fiber materials are commonly used [32]. Hydromulch B may be broken down during the intensive irrigation; so, uneven distribution in the thickness of the mulch can be observed on the ground surface [33, 34].

From the management point of view, the results of this study support the use of hydromulch B as an efficient bioengineering alternative to stabilize hillslopes after road construction. The results from this study could help landscape managers to select and apply more appropriate treatments for soil erosion control from bare slopes of road embankments.

Heavy rainfall and long-term dry period are the most important limitations of this study. So, it is suggested that hydromulching time be set according to climate condition and weather information. May and September months are the suitable time for hydromulching operation in Hyrcanian region of Iran.

Conclusion

Hydromulch B is clearly much more efficient than hydromulch A and traditional seeding in terms of minimizing soil erosion. Traditional mix seeding is not able to promote an effective grass cover to significantly reduce soil erosion from artificial slopes. Hydromulch B provide favorable moisture and soil temperatures for grass seeds and this accelerates plant establishment.

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References

1- Sheldon JC, Bradshaw AD. The development of a hydraulic seeding technique for unstable sand slopes. I. Effects of fertilizers, mulches and stabilizers. J Appl Ecol. 1997; 14(3):905-18.

2- Grace JM. Effectiveness of vegetation in erosion control from forest road sideslopes. Trans ASAE. 2002;45(3):681-5.

3- Liu G, Tian FX, Warrington DN, Zheng SQ, Zhang Q. Efficacy of grass for mitigating runoff and erosion from an artificial loessial earthen road. American Soci Agri Biol Eng. 2010;53(1):119-25.

4- Adekalu KO, Olorunfemi IA, Osunbitan JA. Grass mulching effect on infiltration, surface runoff and soil loss of three agricultural soils in Nigeria. Bioresour Technol. 2007;98(4):912-7.

5- Albaladejo Montoro J, Alvarez Rogel J, Querejeta J, Díaz E, Castillo V. Three hydro-seeding revegetation techniques for soil erosion control on anthropic steep slopes. Land Degrad Dev. 2000;11(4):315-25.

6- Groen AH, Woods SW. Effectiveness of aerial seeding and straw mulch for reducing post-wildfire erosion, north-western Montana, USA. Int J Wildland Fire. 2008;17(5):559-71.

7- Bautista S, Robichaud PR, Bladé C. Post-fire mulching. In: Cerdá A, Robichaud PR. editors. Fire effects on soils and restoration strategies. Volume 5. New Hampshire: Science Publishers; 2009. pp. 353-72.

8- Faucette LB, Risse LM, Nearing MA, Gaskin JW, West LT. Runoff, erosion, and nutrient losses from compost and mulch blankets under simulated rainfall. J Soil Water Conserv. 2004;59(4):154-60.

9- Akbarzadeh A, Taghizadeh Mehrjardi R, Refahi HG, Rouhipour H, Gorji M. Using soil binders to control runoff and soil loss in steep slopes under simulated rainfall. Int Agrophysics. 2009;23(2):99-109.

10- Dodson EK, Peterson DW. Seeding and fertilization effects on plant cover and community recovery following wildfire in the Eastern Cascade Mountains, USA. For Ecol Manage. 2009;258:1586-93.

11- Enriquez A, Carrasco MJ, Varela JM. Monitoring the effectiveness of plant restoration of the slopes of the highways .Civil. 2004;134:27-35.

12- Marques MJ, Bienes R, Jiménez L, Pérez-Rodríguez R. Effect of vegetal cover on runoff and soil erosion under light intensity events. Rainfall simulation over USLE plots. Sci Total Environ. 2007;378(1-2):161-5.

13- Rivera D, Mejías V, Jáuregui BM, Costa-Tenorio M, López-Archilla AI, Peco B. Spreading topsoil encourages ecological restoration on embankments: Soil fertility, microbial activity and vegetation cover. PLOS ONE. 2014;9(7):101-14.

14- Li XH, Zhang ZY, Yang J, Zhang GH, Wang B. Effects of Bahia grass cover and mulch on runoff and sediment yield of sloping red soil in southern China. Pedosphere. 2011;21(2):238-43.

15- Gyasi-Agyei Y. Optimum use of erosion control blankets and waste ballast (rock) mulch to aid grass establishment on steep slopes. J Hydro Eng. 2004;9(2):150-9.

16- Fox JL, Bhattarai SP, Gyasi- Agyei Y. Evaluation of different seed mixtures for grass establishment to mitigate soil erosion on steep slopes of railway batters. J Irrig Drain Eng. 2010;137(9):624-31.

17- Pan C, Shangguan Z. Runoff hydraulic characteristics and sediment generation in sloped grassplots under simulated rainfall conditions. J Hydrol. 2006;331(1-2):178-85.

18-Babcock DL, McLaughlin RA. Runoff water quality and vegetative establishment for groundcovers on steep slopes. J Soil Water Conserv. 2011;66(2):132-41.

19- Holt G, Buser M, Harmel D, Potter K, Pelletier M. Comparison of cotton based hydro-mulches and conventional wood and paper hydro-mulches-study Ⅱ. J Cotton Sci. 2005;9(3):121-7.

20- Babcock DL, McLaughlin RA. Erosion control effectiveness of straw, hydromulch and polyacrylamide in a rainfall simulator. J Soil Water Conserv. 2013;68(3):221-7.

21- Baskin JM, Davis BH, Baskin CC, Gleason SM, Cordell S. Physical dormancy in seeds of Dodonaea viscosa (Sapindales, Sapindaceae) from Hawaii. Seed Sci Res. 2004;14(1):81-90.

22- Phartyal SS, Baskin JM, Baskin CC, Thapliyal RC. Physical dormancy in seeds of Dodonaea viscosa (Sapindaceae) from India. Seed Sci Res. 2005;15(1):59-61.

23- Hossain MA, Arefin MK, Baldip Khan, Rahman MA. Effects of seed treatments on germination and seedling growth attributes of Horitaki (Terminalia chebula Retz.) in the nursery. Res J Agric Biol Sci. 2005;1(2):135-41.

24- Karaguzel O, Cakmakci S, Ortacesme V, Aydınoğlu B. Influence of seed coat treatments on germination and early seedling growth of Lupinus varius L. Pak J Bot. 2004;36(1):65-74.

25- Li L, Xi-ming Z, Runge M, Xiao-ming L, Xing-yuan H. Responses of germination and radicle growth of two Populus species to water potential and salinity. For Stud China. 2006; 8(1): 10-5.

26- Mickovski SB, Van Beek LPH. Root morphology and effects on soil reinforcement and slope stability of young vetiver (Vetiveria zizanioides) plants grown in semi-arid climate. Plant Soil. 2009;324(1-2):43-56.

27- Gobinath R, Ganapathy GP, Akinwumi II. Evaluating the use of lemon grass roots for the reinforcement of a landslide affected soil from Nilgris district, Tamil Nadu, India. J Mater Environ Sci. 2015;6(10):2681-8.

28- Berglund ER. Seeding to control erosion along forest roads. Corvallis: Extension Service, Oregon State University; 1976. p. 20.

29- Coleman R. The case for planting native grasses and wildflowers. Public Works, 1996;127:54-83.

30- Landis TD, Wilkinson KM, Steinfeld DE, Riley SA, Fekaris GN. Roadside revegetation of forest highways: New applications for native plants. Nativ Plant. 2005;6(3):297-305.

31- Vega JA, Fernández C, Fonturbel T. Comparing the effectiveness of seeding and mulching + seeding in reducing soil erosion after a high severity fire in Galicia (NW Spain). Ecol Eng. 2015;74:206-12.

32- Hubbert KR, Wohlgemuth PM, Beyers JL. Effects of hydromulch on post-fire erosion and plant recovery in chaparral shrublands of southern California. Int J Wildland Fire. 2012;21:155-67.

33- Clemente AS, Moedas AR, Oliveira G. Martins-Loução M.A. Correia O. Effect of hydroseeding components on the germination of Mediterranean native plant species. J Arid Environ. 2016;125:68-72.

34- Vourlitis Gl, Griganavicius J, Gordon N, Bloomer K, Grant T, Hentz C. Hydroseeding increases ecosystem nitrogen retention but inhibits natural vegetation regeneration after two years of chaparral post-fire recovery. Ecol Eng. 2017;102:46-54.