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Use of rice husk ash as a stabilizer to reduce soil loss and runoff rates on sub-base materials of forest roads from rainfall simulation tests

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ABSTRACT

The impact of rice husk ash (RHA) as a stabilizer to reduce soil loss and surface runoff rates on sub-base materials of forest roads has been studied using a portable rainfall simulator at an intensity of 52 mmh^{-1}. Thirty rainfall simulations were carried out on different combinations of materials: on the natural sub-base soils (5), on the materials stabilized with pure lime (5), and on the materials stabilized with different percent of RHA and lime (20). Results indicated that on natural sub-base soils, the runoff coefficient was 53.6% and mean time to runoff was 87 s. On the materials stabilized with pure lime, the runoff coefficient and mean time to runoff were measured 58.7% and 63 s, respectively. The lowest runoff coefficient was measured 36.6% on the combination of soil + 6% lime + 9% RHA. However, the highest mean time to runoff was recorded 198 s on the combination of soil + 4% lime + 9% RHA. The maximum and minimum soil loss rates were found on the natural sub-base soils (212.2 g m^{-2}) and on the combination of soil + 6% lime + 9% RHA (162.4 g m^{-2}), mainly due to changes in maximum dry density (MDD), plasticity index (PI), optimum moisture content (OMC) and CBR of materials. On the basis of the results, we concluded that the rice husk ash not only increases the materials quality in soil stabilization methods with lime, but also reduces the runoff and soil loss rates on unpaved forest roads.

1. Introduction

Road-related factors, such as the road construction and timber harvest on unstable soils, dense road networks, poor drainage and inappropriate pavement materials contribute to a high probability of observing changes in peak flows and sedimentation (Selkirk and Riley, 1996; Ramos-Scharron and MacDonald, 2005; Safari et al., 2016). Unpaved forest roads can create an impermeable layer for the initiation of surface flow. Then, large volumes of overland flow may travel downslope toward the stream network (Reid and Dunne, 1984; Croke et al., 1999; Jordán et al., 2009). The rates of soil loss and surface runoff on unpaved forest roads depend on terrain features and topography, geometric design, age of road, hydraulic parameters, drainage condition and traffic volume (Coker et al., 1993; Cao et al., 2009). The most important pavement layer of forest roads (access roads) is sub-base layers, since the construction of base layer on forest roads is not justified according to its standards due to economic situation of forestry projects. Unconsolidated material with poor structure is susceptible to erosion during precipitation events. A stable structure with larger voids in the pavement layer promotes infiltration of water during rainstorms and results in reduced runoff and soil loss (Ziegler et al., 2000). Materials of the pavement layer have an important role on the rates of soil loss and runoff. The production of sediment from the road surface depends on materials of road surface, traffic density, road dimensions and road gradient. Luce and Black (1999) stated that "contributing segment area and road materials are the key controlling factors for road surface-related sediment productions". Sheridan and Noske (2007) found that soil-surface roads contributed 25 times more sediment than gravel paved roads and Demir et al. (2012) stated that total sediment production of unpaved forest road was 1.96 times higher than that of paved forest road.

The materials used for the sub-base layer of forest roads generally contain >12% silt and clay. The kinetic energy of raindrops break up soil aggregates and fine particles detached from soil. The detachment of soil particles can increase the soil erosion after rainstorms (Rimal and Lal, 2009; Jordán et al., 2009). To have the required strength to resist the kinetic energy of raindrops, tensile stresses and strains spectrum the materials used for the sub-base layer should have suitable specification. One way to improve the mechanical properties of these soils is the use of soil stabilizers. Pozzolanic materials such as rice husk ash (RHA) with silica and high specific surface can be used as an inexpensive stabilizer (RHA is not suitable for cattle feeding and it is also non-biodegradable) in soil stabilization method with lime (Chobbasti et al., 2010;

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Weiting et al., 2012). Low cost and availability of RHA have led many researchers to investigate RHA as an alternative for soil stabilization (Basha et al., 2005; Nair et al., 2008; Harichane et al., 2011; Hossain and Mol, 2011; Weiting et al., 2012; Jamil et al., 2013). They stated that addition of lime and RHA can improve the mechanical properties of soil including optimum moisture content (OMC), maximum dry density (MDD), California Bearing Ratio (CBR), unconfined compressive strength (UCS) and plasticity index (PI).

Several studies have reported the effect of pozzolanic materials on mechanical properties' improvement and durability of sub-base soils (Onyango et al., 2007; Alhassan, 2008; Chobbasti et al., 2010; Trivedi et al., 2013). Over the past two decades, many studies have been carried out to determine runoff and soil loss rates from unpaved roads (Reid and Dunne, 1984; Selkirk and Riley, 1996; Ziegler et al., 2001; Arnaez et al., 2004; Jordán and Martínez-Zavala, 2008; Cao et al., 2009; Safari et al., 2016). However, very few studies have been conducted on the impact of pozzolanic materials on runoff and soil loss rates. The aim of this research is to quantify runoff and soil erosion from unpaved forest roads according to the different combinations of sub-base materials. In this work, rainfall simulation tests were used to (a) study the hydrological and erosive response from different combinations of sub-base materials (soil, lime and rice husk ash) and (b) correlate these data to the soil mechanical properties of materials.

2. Materials and method

2.1. Study area

This study was carried out in a road of Caspian forest (Azarrood basin), in northern Iran, approximately on the coordinates 36° 19′ 72″ N and 52° 83′ 22″ E. In this region, there is a moderate mountainous climate with cold winters and humid summers and the mean annual rainfall is about 800 mm. Alborz earth dam with a height of 72 m was constructed below the confluence of several rivers including the Skelimrood, Azarrood and Karsangrood (Fig. 1,a). Total length of forest roads (surrounding the Alborz dam) and density of these roads are 17 km and 10.5 m per hectare, respectively. There is low-volume of traffic on these roads by forestry machinery. However, this network is used

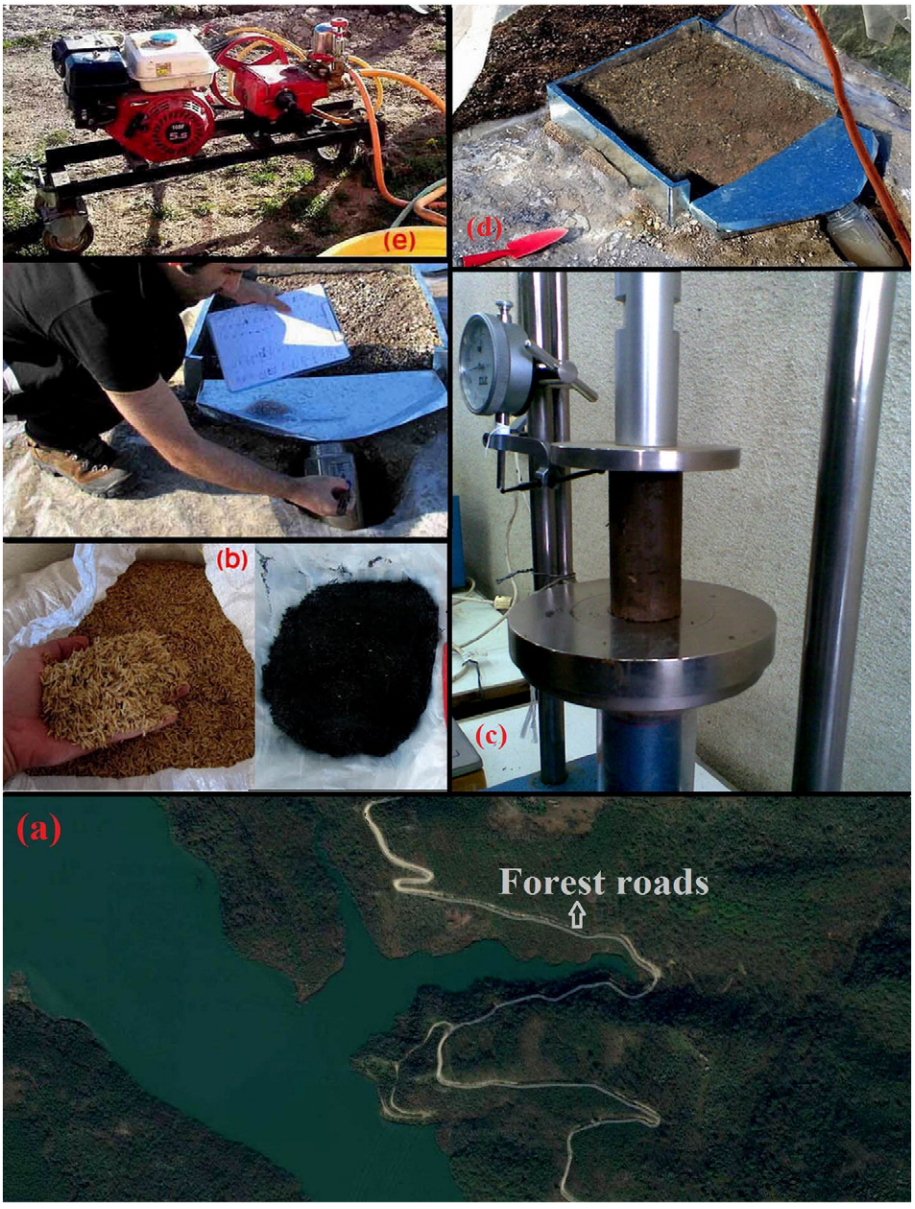

Fig. 1. Alborz earth dam and construction of forest roads in the Azarrood forest of Iran (a); produced RHA and rice husk (b); laboratory tests (unconfined compression apparatus(Afrazma)) to identify specification of different combinations (c); rainfall simulations to measure the runoff and soil loss (d) and use of mobile pump for field experiments (e).