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Research article

Combined effects of polyacrylamide and nanomagnetite amendment on soil and water quality, Khorasan Razavi, Iran

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ABSTRACT

Nanotechnology is increasingly being used to remediate polluted soil and water. However, few studies are available assessing the potential of nanoparticles to bind surface particles, decrease erosion, and minimize the loading of water pollutants from agricultural surface discharge. To investigate this potential, we treated in situ field plots with two practical surface application levels of anionic polyacrylamide (PAM only) with and without nanomagnetite (PAM-NM), examined soil physical properties, and evaluated the impact of this amendment on contaminant sorption and soil erosion control. Polyacrylamide and PAM-NM treatments resulted in 32.2 and 151.9 fold reductions in Mn^{2+}, 1.8 and 2.7 fold for PO_4^{3-}-P, and 2.3 and 1.6 fold for NH_4^+-N, respectively, compared to the control. Thus, we found that the combination of PAM and NM, had an important inhibitory effect on NH_4^+-N and PO_4^{3-}-P transport from soil—pollutants which can contribute substantially to the eutrophication of surface water bodies. Additionally, since the treatment, especially at a high concentration of NM, was effective at reducing Mn^{2+} concentrations in the runoff water, the combination of PAM and NM may be important for mitigating potential risks associated with Mn^{2+} toxicity. Average sediment contents in the runoff monitored during the rainfall simulation were reduced by 3.6 and 4.2 fold for the low and high concentration PAM-NM treatments when compared to a control. This treatment was only slightly less effective than the PAM-only applications (4.9 and 5.9 fold, respectively). We report similar findings for turbidity of the runoff (2.6–3.3 fold for PAM only and 1.8–2.3 fold for PAM-NM) which was caused by the effects of both PAM and NM on the binding of surface particles corresponding to an increase in aggregate size and stability. Findings from this field-based study show that PAM-modified NM adsorbents can be used to both inhibit erosion and control contaminant transport.

1. Introduction

Soil erosion and contaminant transport are among the processes that most threaten the quality of soil and water resources in Iran (Jahanjo, 2000; Agheli-e Kohneshari and Sadeghi, 2005; AQUASTAT, 2008). Contamination levels in runoff water can greatly affect surface water toxicity and, thus, the health of aquatic ecosystems (Reimer, 1999; ESRD, 2014). In addition, soil erosion diminishes soil fertility (Noor et al., 2013; Fu and Chen, 2000; Mafongoya et al., 2006), reducing the water-storage capacity of reservoirs (Rahmanian and Banihashemi, 2011; Wisser et al., 2013) and causing eutrophication (Jennings et al., 2003; Uwimana et al., 2017) as sediments and nutrients are lost by agricultural runoff and transported downstream. In Iran, reservoirstorage volume reduction is 1.65% annually, more than the average annual loss in the world (0.96%) (ICOLD Committee, 2009). Eutrophication of the Torogh reservoir in Iran, which supplies drinking water to approximately 3.4 million people in Mashhad, Khorasan Razavi Province, and supports agricultural irrigation in the area, is due to extensive use of fertilizers in the associated basin and subsequent erosion and runoff (Heydarizad, 2018). Thus, better environmental management strategies are required given the extent of soil and water contamination in this region. In particular, the development of new

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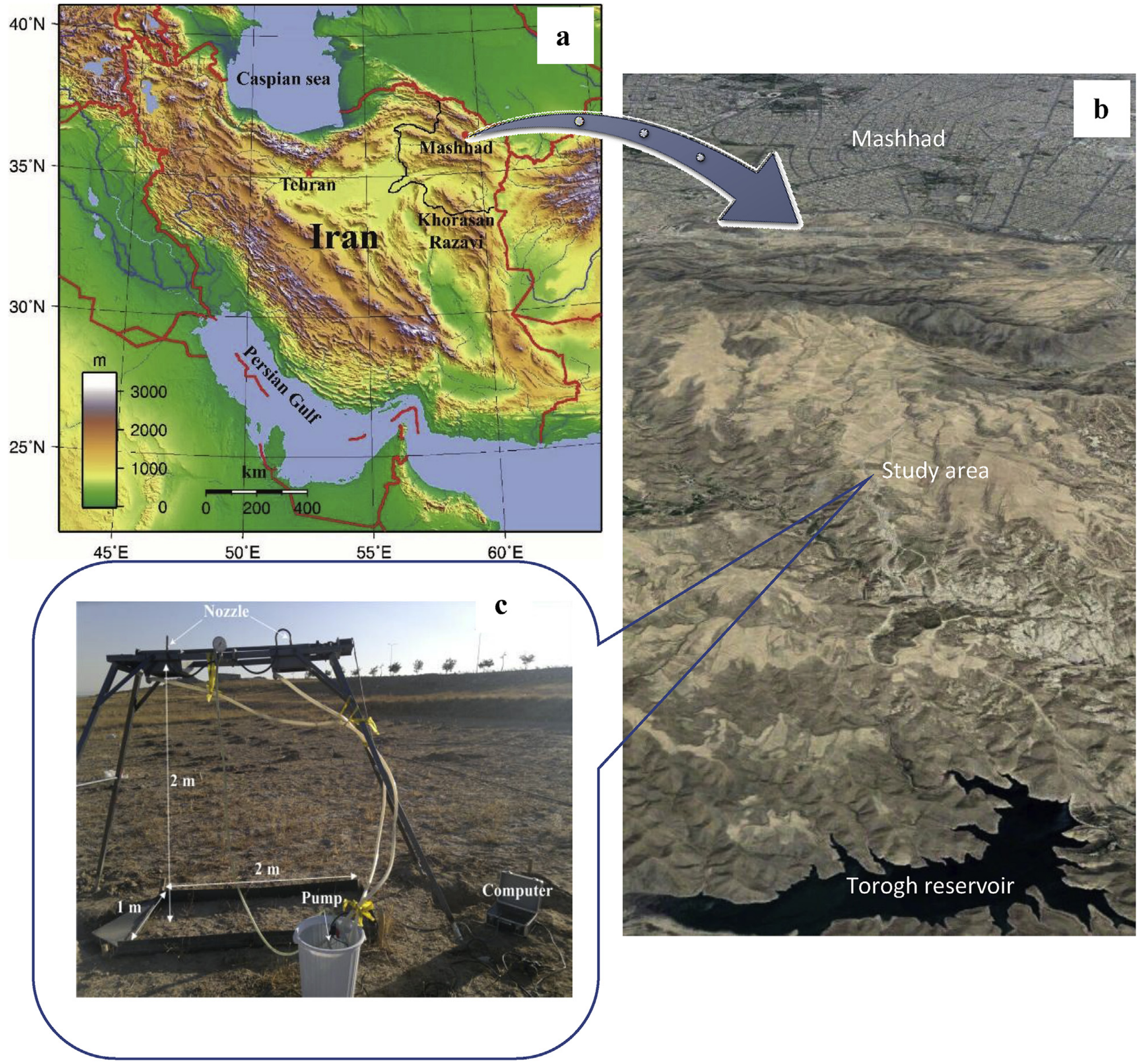

Fig. 1. (a) General shaded relief map of Iran showing the location of Khorasan Razavi (Sadalmelik, 2007). (b) Oblique image showing the location of the study area in relation to the Torogh reservoir and the City of Mashhad (Source: 36°12′22.50″ N and 59°32′35.81″ E, Google Earth, image date: 20 April 2018; accessed 10 June 2018). (c) Photograph of the rainfall simulator and experimental setup.

strategies and/or technology for the combined management of soil erosion and runoff contamination is crucial for mitigating future degradation of soil and water quality in this region.

A variety of methods have been employed to minimize nutrient concentration in runoff, reduce water and sediment discharge, and protect soil from erosive forces through the creation and maintenance of soil aggregates which serve to stabilize the surface via increased interaggregate particle-to-particle binding strengths (Orts et al., 2007) and intraaggregate pore networks, which improve infiltration, reduce runoff and, thus, sediment load (Mamedov et al., 2007). One such technology employs non-oil polymeric mulches, such as acrylamide-based polymers, because of its low cost and soil fertility benefits (Kurenkov and Myagchenkov, 1996; Sojka et al., 2007). Water-soluble cationic and neutral polyacrylamides are toxic and are usually avoided in environmental applications but the anionic polyacrylamide (PAM) $[(H_2{-}CH{-}CO{-}NH_2)_n]$ used in agriculture is generally considered environmentally safe (Seybold, 1994; Entry et al., 2002; Sojka and Entry, 2000; Sojka et al., 2007; Weston et al., 2009) as evidenced by its wide use in the food industry, mineral processing, and municipal water treatment as a settling agent (Barvenik, 1994).

The molecular properties (large molecular weight and charge density) of PAM allow it to be used to effectively flocculate clay particles, stabilize soil aggregates, diminish the formation of surface sediment seals, mitigate erosion, increase plant available water, improve drainage, and enhance the removal of salts, nutrients, pesticides, microorganisms, and weed seeds from water and runoff (Green et al., 2000; Sojka et al., 2004; Sivapalan, 2006; Sparks, 2007; Blanco and Lal, 2008) and as a consequence, improve water quality (Ajwa and Trout, 2006; Guzzo and Guezennec, 2015). Polyacrylamide strengthens the bonds between soil particles through coulombic and van der Waals forces (Orts et al., 2007). Effectiveness of PAM, however, depends on a number of factors including soil texture, rainfall and runoff characteristics, soil management, mineralogy and extractable Fe (McLaughlin and Bartholomew, 2007; Blanco and Lal, 2008).

In recent years, magnetite nanoparticles have received attention as a new soil remediation technology due to its strong affinity for heavy metals and nutrients, high magnetic susceptibility, non-toxicity, biocompatibility, low cost of production and chemical stability over a wide