Research article

Erosion Control by Amending Soil with Gypsum in the Dawlatzai Village of Gardez District, Afghanistan

ABDUL MALIK DAWLATZAI
Graduate School of Agriculture, Tokyo University of Agriculture, Tokyo, Japan
Email: abduldawlatzai@gmail.com

MACHITO MIHARA
Faculty of Regional Environmental Science, Tokyo University of Agriculture, Tokyo, Japan

TAKAHIKO NAKAMURA*
Faculty of Regional Environmental Science, Tokyo University of Agriculture, Tokyo, Japan
Email: ntaka@nodai.ac.jp

SHAFIQULLAH RAHMANI
Graduate School of Agriculture, Tokyo University of Agriculture, Tokyo, Japan

Received 31 December 2017 Accepted 15 October 2018 (*Corresponding Author)

Abstract Minimizing soil and water loss in agricultural land, particularly in arid and semi-arid climatic conditions, is indispensable for environmental protection and agricultural production. The purpose of this research is to evaluate the effectiveness of gypsum application in reducing sediment concentration in runoff and total soil loss. A field experiment was conducted in the village of Dawlatzai in Gardez District, Paktya, Afghanistan. Using a portable rainfall simulator, four erosion plots; gypsum-treated, clover, maize, and control were designed and applied in two replications. Surface runoff experiment using sandy loam and loamy soil textures was conducted in the Laboratory of Land and Water Use Engineering, Tokyo University of Agriculture. Gypsum mineral was applied at a rate of 5 t ha^{-1} for both experiments. The results of field experiments showed that the gypsum-treated, clover and maize fields reduced total soil loss by 67.28%, 92.04% and 54.45% compared to the control, respectively. Likewise, surface runoff was reduced by 19.62% in the gypsum-treated field compared to the control field. Similarly, the results of laboratory experiment showed that with application of gypsum, surface runoff was reduced by 38.83% and 37.07% from sandy loam and loamy soil textures with total soil loss reduced by 60.25% and 81.86% compared to control, respectively. Percolation was increased by 2.31 and 2.29 times in sandy loam and loamy soil textures, respectively. Moreover, the application of gypsum significantly reduced sodium adsorption ratio (SAR) and boosted the calcium content and flocculation phenomena. Based on these results, it can be suggested and recommended that farmers in Paktya should apply gypsum mineral to their farmlands to enhance water infiltration and minimize surface runoff and soil loss.

Keywords gypsum, infiltration, soil loss, village of Dawlatzai

INTRODUCTION

Gypsum mineral is generally used mostly because of its availability and low-cost. Gypsum has an ability to minimize clay dispersion, thereby permeability of the soil and increases the stability aggregates at the soil surface. However, the major benefits of gypsum mineral related to agriculture includes; source of calcium and sulphur for plant nutrition, improves acid soils and treats aluminum toxicity, enhances soil structure, increases water infiltration and reduce runoff and soil loss (Greenleaf Advisors, 2015; US-EPA, 2008; Hopkins, 2013).

Gypsum mineral from by-product of industrial processing called synthetic gypsum. It is composed of calcium sulphate dihydrate and similar in characteristics to natural gypsum and is environmentally friendly. Ameliorating saline-sodic soils are indispensable for suitable agriculture and clay dispersion. Therefore, gypsum is used for sodic soil reclamation, because it is calcium-rich, dissolves at high pH and replaces of sodium from an exchange site (Horneck et al., 2007).

Gypsum mineral is able to improve soil hydraulic conductivity and significantly increases infiltration conditions (Miller, 1987). Gypsum dissolves quickly and releases electrolytes thus flocculate the soil particles and lower tendency of clay to disperse (Shainberg et al., 1989). The objective of this study is to evaluate the effectiveness of gypsum application in reducing sediment concentration in runoff and total soil loss.

MATERIALS AND METHODS

Study Site

The research was conducted in the Dawlatzai Village of Gardez District, Paktya Province, Afghanistan (Fig. 1). The village is about 5 km from south of Gardez city, which is the capital of Paktya Province. About 1,850 families live in the village and 80% of the population depends on agriculture and animal husbandry for livelihood.

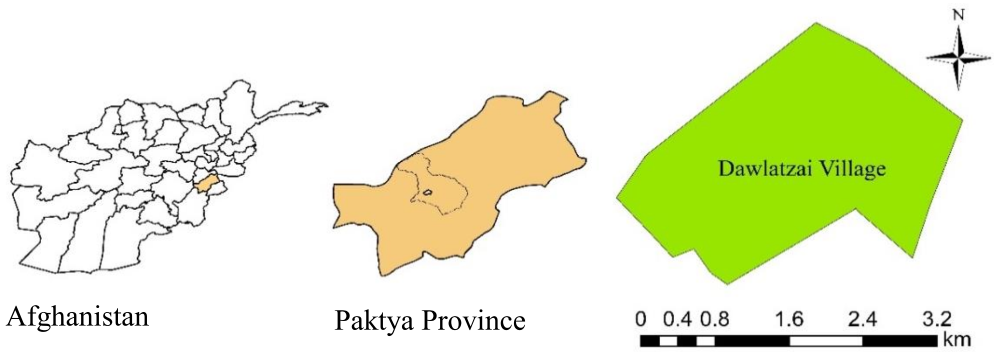

Fig. 1 Dawlatzai Village in Gardez District, Paktya Province, Afghanistan

Field Experiment

A field experiment with four erosion plots; gypsum-treated, clover, maize, and control were designed and applied in two replications. Using a portable artificial rainfall simulator; raindrop sizes approx. 3.42 mm, kinetic energy about 1.6×10^{-5} J and Marriotte bottle generated constant pressure at 981 Pa (Maore and Mihara, 2017). Gypsum mineral was applied at the rate of 5 t ha^{-1}. Runoff collector was installed on the downstream side, depending on the direction of sloppy field. The soil was pre-wetted for 24 hours before application of artificial rain (Fig. 2). Surface runoff was collected at an interval of 5 minutes for a duration of 30 minutes. It was analyzed for chemical and physical properties in laboratory of Land and Water Use Engineering, Tokyo University of Agriculture.

Laboratory Experiment

Similarly, the surface runoff experiment was conducted in the laboratory of Land and Water Use Engineering using a triangular erosion plot. The length was 91.0 cm, and width 3.0 cm and height are 2.5 cm. The slope of a plot was arranged as 8.0° (Fig. 3). Soil was used for the erosion plot compacted under a dry density of 1.61 g/cm^3 and 1.47 g/cm^3 for sandy loam and loamy soil textures, respectively. Marriotte bottle with constant pressure was used to supply water during 30 minutes. Surface runoff and percolation water were collected at 5 minutes interval. Two treatments were applied; control and gypsum-treated. Gypsum was applied at the rate of 5 t ha^{-1}. Soil was saturated for 24 hours before the experiment. The surface runoff was analysed for calcium, magnesium, sodium, and soil loss. In addition, flocculation and dispersion experiments were conducted; using loamy soil texture and gypsum mineral was applied at rates of 2.5 t ha^{-1}, 5 t ha^{-1}, 7.5 t ha^{-1}, and 10 t ha^{-1}. Soil and gypsum were put into tubes and added 100 ml deionized water, then shaken mechanically for a minute. Samples were taken after an interval of 1 hour and experiment were run for 4 hours.

Fig. 2 Diagram of field experiment

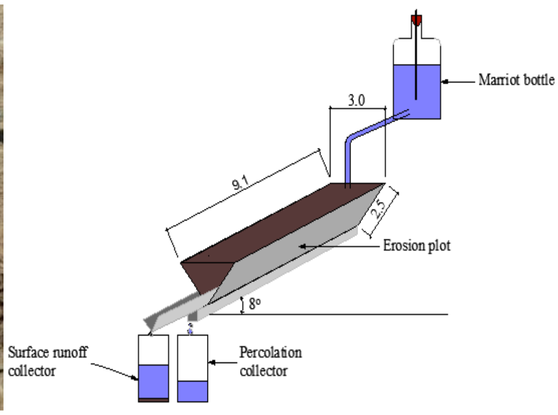

Fig. 3 Diagram of surface runoff experiment

RESULTS AND DISCUSSION

The results of field experiments showed that, the total surface runoff for all treatments' gypsum treated, clover, maize and control fields was at 3.40 L, 3.06 L 4.01 L and 4.23 L, respectively. Statistical analysis showed that there were significant differences ($P<0.05$) between gypsum-treated and clover fields, and control and maize fields (Fig. 4). Application of gypsum reduced surface runoff 19.62%. Total soil loss of gypsum-treated, clover and maize fields were reduced by 67.28%, 92.04% and 54.45% compared to control, respectively (Table 1). Gypsum has been used for reducing and controlling crust formation on the soil surface and improving water infiltration as well as stabilizing sodic soil (Agassi et al., 1981; Miller, 1987).

Table 1 Soil loss in each field

Treatment	Average soil loss (t ha^{-1})	Total soil loss, reduced from control (%)
Gypsum	4.11	67.28
Clover	1.00	92.04
Maize	5.72	54.45
Control	12.56	

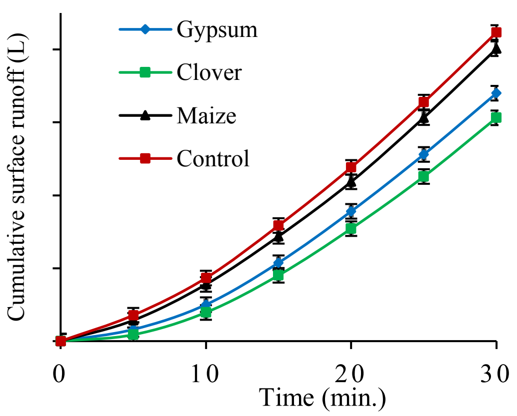

Fig. 4 Changes in surface runoff with time

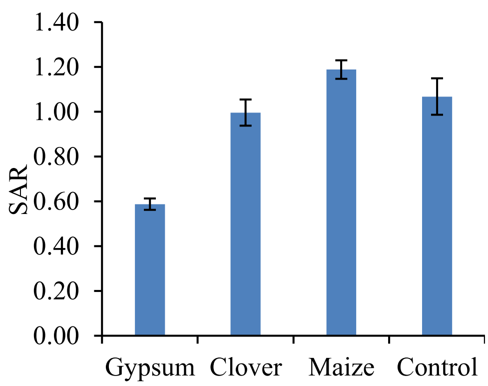

Fig. 5 SAR of surface runoff

Sodium adsorption ratio (SAR) expresses the relationships between sodium content and calcium plus magnesium contents (Eq. 1). This ratio reflects the amounts of sodium adsorbed onto clay and soil organic matter exchange surfaces, hence the potential for flocculation or dispersion processes within the soil (Keren, 1991). These processes influence the hydraulic properties of the soil, runoff and soil erosion (Lavee et al., 1991). The higher the SAR, the more likely the soil is to disperse, but low SAR soils tend to flocculate. In dispersed soils, water infiltrates and drains slowly, the water runs off the soil, increasing the potential for erosion and limiting amount of the water available for crops and soil become very poorly aerated due to inadequate of the large pores. However, the application of gypsum significantly reduced SAR value. SAR value for all treatments' gypsum-treated, clover, maize and control fields were as of 0. 59, 1.00, 1.19 and 1.07 (Fig. 5).

$$\mathrm{SAR} = \frac{[Na^{+}]}{\sqrt{\frac{[Ca^{+2} + Mg^{+2}]}{2}}} \qquad (1)$$

Table 2 shows that the application of gypsum mineral slightly increased EC of soil solution because the gypsum mineral is sparingly soluble salt. However, it did not change the pH of the soil solution. Gypsum improves chemical properties of soil such as aluminium toxicity caused by subsoil (Chen and Dick, 2011). Gypsum is a neutral salt and not a liming agent, therefore, does not neutralize the hydrogen ion in the soil solution (Fisher, 2011).

Table 2 Electrical conductivity and pH of surface runoff

No	Treatment	EC (mS/m)	pH
1	Gypsum	77.88	7.78
2	Clover	67.13	7.87
3	Maize	59.11	7.97
4	Control	55.03	7.79

Total surface runoff for gypsum-treated plots was at 0.63 L and 0.73 L and for control plots were 1.03 L and 1.16 L. The results showed the application of gypsum significantly reduced runoff by 38.83% for sandy loam soil and 37.07% for loamy soil compared to the control (Table 3). Likewise, the total percolating water for gypsum-treated plots was at 0.81 L and 0.35 L and for control plots; 0.71 L and 0.31 L. The application of gypsum increased percolation rate by 2.31 times for sandy loam soil texture and 2.29 times for loamy soil texture compared to the control (Table 4). Mahardhika et al., (2008) reported, they applied gypsum mineral at a rate of 10 t ha^{-1}, polyacrylamide (PAM) 40 kg ha^{-1} and combined application of both amendments (PAM + gypsum) at the same rates. Total soil loss was reduced by 39%, 43%, and 74%, compared to the control. The application of PAM + gypsum more significantly was reduced soil to compare with other treatments. The application of gypsum mineral was effective in considerably reducing total soil loss from agricultural land.

Table 3 Changing surface runoff from the control

Soil texture	Treatment	Total discharge (L)	Total surface decreased from control (%)
Sandy loam soil	Gypsum	0.63	38.83
	Control	1.03	
Loamy soil	Gypsum	0.73	37.07
	Control	1.16	

The results in Table 5 indicated, the application of gypsum significantly reduced the total soil loss by 60.25% and 81.86% for sandy loam and loamy soil textures, respectively compared to control. As well, significantly reduced SAR value by 59% and 52% and increased the calcium content for both soil textures (Fig. 6 and Fig. 7), although, the calcium concentration a slightly more for loamy soil texture because of Cation Exchange Capacity (CEC) of soil. Gypsum mineral boosted soil condition and improved crop yields as well as increasing the sulphur content which is an essential nutrient for plant growth (Chen and Dick, 2011). Calcium ion is very important for cell walls, membrane and developing root growth (Fisher, 2001).

Table 4 Changing percolation from the control

Soil texture	Treatment	Total percolation (L)	Total percolation changed from control (time)
Sandy loam soil	Gypsum	0.81	2.31
	Control	0.35	
Loamy soil	Gypsum	0.71	2.29
	Control	0.31	

Table 5 Soil loss from sandy loam and loamy soil textures

Soil	Treatment	Average total soil loss (t ha^{-1})	Total soil loss decreased from control (%)
Sandy loam soil	Gypsum	16.98	60.25
	Control	42.72	
Loamy soil	Gypsum	5.34	81.86
	Control	29.50	

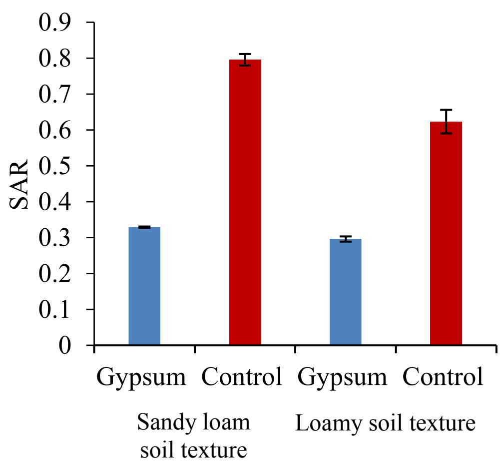

Fig. 6 SAR of surface runoff

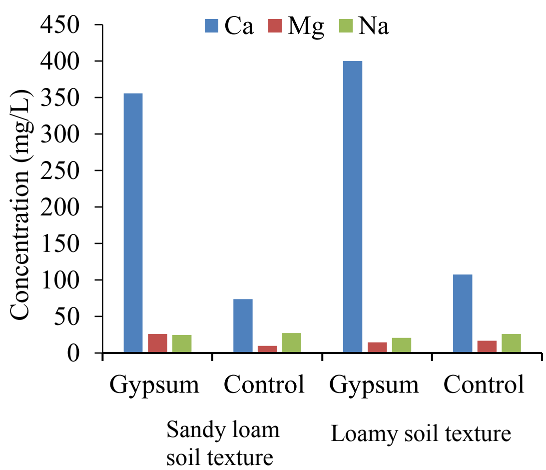

Fig. 7 Cation concentration in surface runoff

Fig. 8 Flocculation and dispersion results

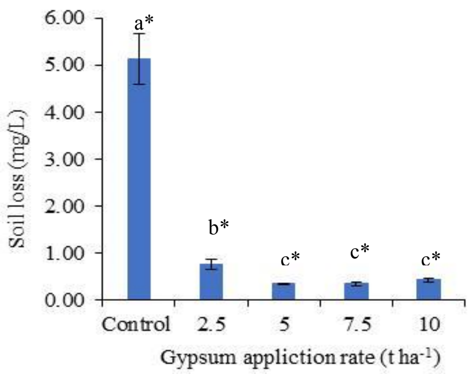

Fig. 9 Effects of gypsum on suspended soil

Flocculation is the process by which clay particles, individual coagulate or aggregate, water easy moves mostly in large pores between in aggregates. The dispersion is the reverse action of flocculation clay plug soil pores over enhances surface runoff and reduces water infiltration and drainage thereby increases soil erosion (Bratby, 1980). Gypsum is known to flocculate the soil and pull together clay particles an aggregate. The results indicated the addition of gypsum mineral at the rates of 2.5 t ha^{-1}, 5 ha^{-1}, 7.5 ha^{-1}, and 10 ha^{-1} significantly ($P<0.05$) flocculated soil particles compared to the control. Furthermore, there is a negligible differential between high and low rates of gypsum application (Fig. 8 and Fig. 9). It means the application of high rate gypsum mineral similar affected as medium rate and the application high-rate of gypsum is uneconomical for farmers.

CONCLUSION

The results could be concluded that the total soil losses from gypsum-treated field, clover field and maize field were reduced by 67.28%, 92.04%, and 54.45% compared to the control and reduced surface runoff by 19.62% for gypsum-treated field compared to the control field. Similarly, it significantly reduced surface runoff by 38.83% for sandy loam soil and 37.07% for loamy soil compared to the control, increased the percolation rate by 2.31 times and 2.29 times and the total soil loss was reduced by 60.25% and 81.86%, from sandy loam and loam soil textures, respectively. By the application of gypsum mineral significantly reduced SAR value and boosted the calcium content. It was considered that gypsum mineral addition is effective in enhancing flocculation and aggregated of soil clay particles and reduce soil loss. The improved surface conditions in the gypsum-treated soil contributed towards reduction in sediment concentration in surface runoff and total soil loss. Accordingly, it is suggested and recommended that farmers in Paktya Province apply gypsum mineral into their farmlands for reducing surface runoff and soil loss.

ACKNOWLEDGEMENTS

The authors are profoundly grateful to Department of Agriculture Engineering, Tokyo University of Agriculture and Japan International Cooperation Agency (JICA).

REFERENCES

Agassi, M., Shainberg, I. and Morin, J. 1981. Effect of electrolyte concentration and soil sodicity on infiltration rate and crust formation. Soil Science Society of America Journal. 45, 848-851.

Bratby, J. 1980. Coagulation and flocculation with an emphasis on water and wastewater treatment. Filtration and Separation, Uplands Pess LTD Publishers, UK.

Chen, L. and Dick, W.A. 2011. Gypsum is an agricultural amendment. General Use Guidelines, Ohio State University, USA.

Fisher, M. 2011. Amending soils with gypsum. Crops and Soil Magazine, USA.

Greenleaf Advisors. 2015. Gypsum for agricultural use. The State of the Science, Bridging Enterprises for a Healthy and Sustainable World.

Hopkins, M. 2013. The role of gypsum in agriculture and five key benefits. http://www.croplife.com/crop-inputs/micronutrients/the-role-of-gypsum-in-agriculture-5-key-benefits-you-should-know.

Horneck, D.A., Ellsworth, J.W., Hopkins, B.G., Sullivan, D.M. and Slevens, R.G. 2007. Managing salt-affected soils for crop production. PNW 601, E, November 2007.

Keren, R. 1991. Specific effect of magnesium on soil erosion and water infiltration. Soil Science Society of America Journal, 55, 783-787.

Lavee, H., Imeson, A.C., Pariente, S. and Benyamini, Y. 1991. The response of soils to simulated rainfall along a climatological gradient in an arid and semi-arid region. Catena, 19, 19-37.

Mahardhika, H., Ghadiri, H. and Yu, B. 2008. Effects of polyacrylamide and gypsum on soil erosion and sediment transport. Griffith University, Nathan, Queensland, Australia.

Maore, J.M. and Mihara, M. 2017. Development of portable artificial rainfall simulator for evaluation sustainable farming in Kenya. International Journal of Environmental and Rural Development, 8 (1), 27-33.

Miller, W.P. 1987. Infiltration and soil loss of three-gypsum amended Ultisols under simulated rainfall. Soil Science Society of America Journal. 51, 1314-1320.

Shainberg, I., Sumner, M.E., Miller, W.P., Farina, M.P.W., Pavan, M.A. and Fey, M.Y. 1989. Use of gypsum on soils. Contribution from the Department of Agronomy, University of Athens Georgia, Advances in Soil Science, 9, 43-50.

UN-EPA. 2008. Agricultural uses for flue gas desulfurization (FGD) gypsum. United States - Environmental Protection Agency, National Service Centre for Environmental Publications, USA.