Visualizing clogging up of soil pores in the tropical degraded soils and their impact on green water productivity

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Abstract

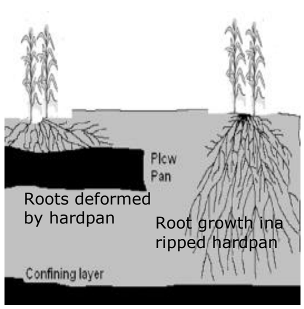
Restrictive soil layers commonly known as hardpans restrict water and airflow in the soil profile and impede plant root growth below the plow depth. Preventing hardpans to form or ameliorate existing hardpans will allow plants root more deeply, increase water infiltration and reduce runoff, all resulting in greater amounts of water available for the crop (i.e. green water). However, there has been a lack of research on understanding the influence of transported disturbed soil particles (colloids) from the surface to the subsurface to form restrictive soil layers, which is a common occurrence in degraded soils. In this study we investigated the effect of disturbed soil particles on clogging up of soil pores to form hardpans. Unsaturated sand column experiments were performed by applying 0.04 g/ml soil water solution in two sand textures. For each experiment, soil water solution infiltration process was visualized using a bright field microscope and soil particles remained in the sand column was quantified collecting and measuring leachate at the end of the experiment in the soil and water lab of Cornell University. Preliminary results show that accumulation of significant amount of soil particles occur in between sand particles and at air water interfaces, indicating the clogging of soil pores occurs as a result of disturbed fine soil particles transported from the soil surface to the subsurface.

Key Words: Soil pore clogging; Hardpans; Green water productivity

Introduction

The Ethiopian highlands receive a high amount of rainfall ranging between 1200 to 2200 mm per year. However, 50 percent of this rainwater is lost as surface runoff FAO (2003) resulting in moisture stress in crop production causing a decrease in crop yields. The presence of restrictive soil layers commonly known as hardpans in the soil profile is one of the known causes of saturation excess runoff production. Hardpan soils are located 10 to 60 cm below the soil surface and restrict water and airflow in the soil profile. These layers impede root growth below the plow depth, thereby reducing plant's capacity to obtain water and nutrients when soil moisture and nutrient reserves in the lower profile are critically needed for crop production Busscher and Bauer (2003); Tekeste (2006), which thereby reduce crop yields. This issue is of a particular concern in the Ethiopian highlands where soils have become eroded and degraded due to increased land use arising from increasing population pressure, leading to clogging of soil pores resulting in formation of restrictive soil layers.

a



b

Figure 1: a) Plant root deformed by a hardpan (left) and plant root growth in a ripped hardpan (right) (FAO, 2005) b) compacted soils in the upper 60 cm above the macro pore networks in a soil profile in the Ethiopian highlands.

Preventing hardpans to form or ameliorate existing hardpans will allow plants root more deeply, increase water infiltration and reduce runoff, all resulting in greater amounts of water available for the crop (i.e. green water). However, there has been a lack of research on understanding the influence of transported disturbed soil particles (colloids) from the surface to the subsurface to form restrictive soil layers, which is a common occurrence in degraded soils. Thus, in this study we investigated the effect of disturbed soil particles on clogging up of soil pores to form hardpans.

Methods

To elucidate hardpan formation processes, unsaturated sand column infiltration measurements were performed in the soil and water laboratory of Cornell University. Acrylic columns made up of glass with dimensions of 2x2x20 cm were used to facilitate visualization of the infiltration processes. The columns were packed with 30 g of two sand textures collected from (Unimin Corporation, Le Sueur, MN, USA). The finer sand texture was with a diameter of 0.00025-0.000425mm and the relatively coarser sand texture was with a diameter of 0.000425-0.000625mm. The experimental set up is shown in Fig.2below.The sand columns were exposed to constant influent (soil-DI water solution considered as rainfall) rate of 0.5 ml/min for an hour and half controlling the inflow rate by a peristaltic pump .Air dried soil samples that were collected in the Debre Mewi watershed, located 30 km in the south of Lake Tana, Ethiopia were used to prepare the soil solution. The characteristics of infiltration measurements are shown in Table 1.

The leachates, draining from the sand column, were collected in cuvettes at five minute intervals at a five cm suction that was controlled by the bubble tower. Concurrently, transportation, circulation and deposition of clay particles (soil colloids) were visualized using a bright field microscope (KH-7700, Hirox-USA, River Edge, NJ, USA). The microscope used the MXG-5040RZ lens with a variable angle lighting adapter (AD-5040SS). Time series images were taken at three different depths and short videos were captured to see the lateral view of the soil-sand interface, the vertical movement of soil solution and clogging up of pores. After finishing the experiments 1 cm soil layers were taken from the columns and washed with 5 ml of water. Sediment concentration in the leachate and the wash water was measured by determining the absorbance of radiation at a wave length of 590 nm with a spectrophotometer.

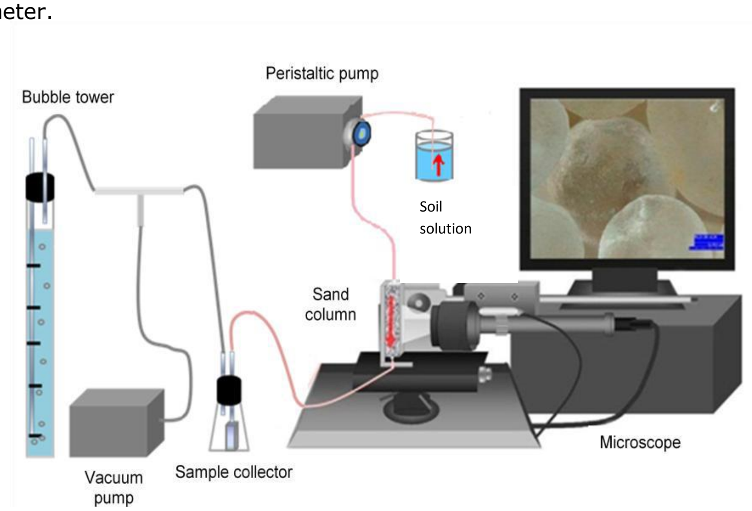


Figure 2: Illustration of infiltration measurement showing the microscope connected to the camera capturing the vertical movement of soil solution in the column. The peristaltic pump is used to regulate the flow rate into the column and the suction by bubble tower is used to regulate regular leachate collection in the sample collector: Image adapted from Sang (2012).

Table 1: The characteristics of infiltration measurements in columns with relatively fine and coarse sand

	Fine sand texture sand column	Relatively coarse sand texture sand column
Sand size (mm)	0.00025-0.000425	0.000425-0.000625
Mass of clay soil added (g)	2	2
Volume of water added(ml)	50	50
Mass of sand in the column(g)	30	30
Inflow rate(ml/min)	0.5	0.5
Time to collect the first leachate(minutes)	17	21

Results and Discussion

Time series microscope images showed that accumulation of significant amount of soil particles occur in between sand particles and at air water interfaces, indicating the clogging of soil pores as a result of disturbed fine soil particles transported from the soil surface to the subsurface. Time series images for infiltration measurements on columns packed with sand texture of 0.000425-0.000625mm diameter are shown in Fig. 3. The first three consecutive pictures were taken at the start of soil solution (0.04g/ml) application, 30 minutes of soil solution application and 1 hour application respectively. The fourth picture at the right end was taken 2 hours after the second soil solution infiltration on the previous sand column. Note that in the third pictures soil colloids are retained in the sand particles while in the fourth picture accumulation of soil particles occurred in the air water interfaces. Repeated rainfall applications have shown an increased accumulation of clay particles with time.

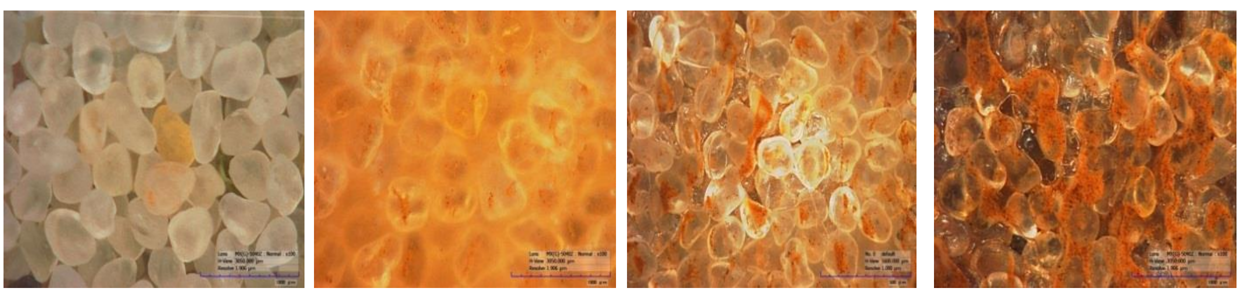


Figure 2: Microscope image of infiltration measurement showing the sand column at the start of the measurement, 30 minutes of soil solution application, 1 hr application and 2 hrs after the second soil solution infiltration on the previous sand column respectively.

Spectrophotometer measurements of the drainage water of the columns (Figure 5)indicated that higher light absorbance was observed in the beginning of infiltration measurements than at the end of the infiltration, indicating higher amount of clay particles were drained and lower amount of clay particles were retained at the beginning. A decrease trend in the light absorbance graph in Figure 5 suggests a decrease in leachate sediment concentration with time and less light absorbance indicating the occurrence of clogging up of pores in between sand particles. In the finer texture sand column, ponding was observed in repeated infiltration measurements of a column and less clay was being eluted and deposited in the sand.

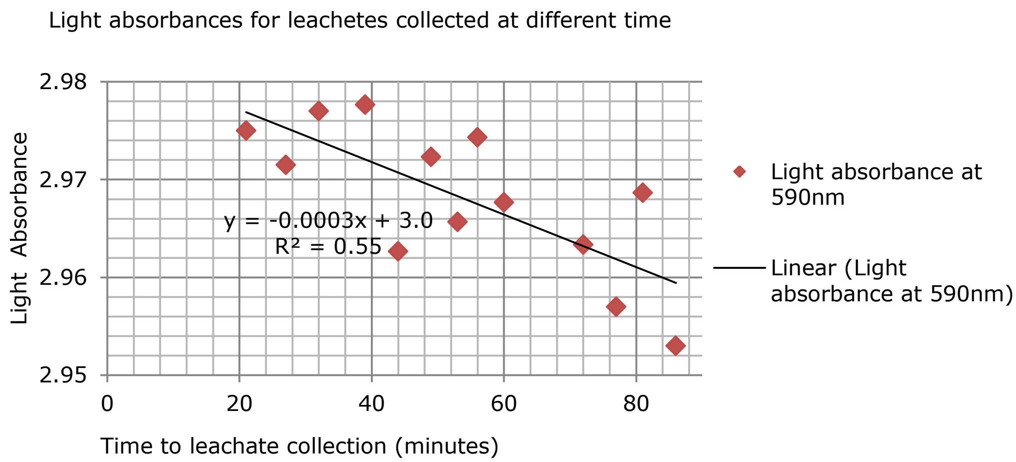


Figure 5: Light absorbance plotted against leachates collection time. The first leachate was collected at the 21st minutes from the beginning of the infiltration measurement.

Our experiments show that forming of the hardpan in the Ethiopian soils can be related to the infiltration of sediment rich water after the soils are tilled and the soil cover is removed by plowing. In addition these experiments show that clay attachment can occur by reclogging but also at the air soil interface or the point where the meniscus attaches to the grain. These particles can be attached firmly against the clay particles by the capillary forces associated with the meniscus. The visualization studies confirm hypothesis of Goldberg (1990), Frenkel et al. (1992), and Lieffering and McLay (1996) that clay soils contribute to blocking of soil pores by deflocculation and movement of clay particles into the conducting pores as discussed above. When such processes repeat year after year, this pore clogging by clay particles inhibits water flow in the soil profile resulting in rainwater loss as surface runoff. Further infiltration measurements are in progress considering variables, such as the role of clay mineralogy, moisture condition, sand diameter size, and infiltration rate on clogging up of soil pores.

Conclusions and Recommendations

Clogging up of soil pores as a result of disturbed fine soil particles transported from the soil surface to the subsurface can significantly reduce water flow in the soil profile resulting in rainwater loss as surface runoff. Improving the productivity of rain fed agriculture system in Ethiopia requires either ameliorating of these pores clogging or preventing them to form. Ameliorating measures include biological and mechanical practices such as planting deep rooted and bio fuel crops and deep tillage practices while preventing measures includes a decrease in intensity of tillage that results in destabilization of soil aggregates and disruption of pore spaces within or between soil aggregates.

Acknowledgments

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