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Research Note

# Impact of Land Management Practices on Runoff, Soil Loss and Infiltration Under Simulated Rainfall

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**ABSTRACT**

A laboratory study was conducted to quantify the effects of various land management practices on runoff, soil loss and infiltration under simulated rainfall conditions. A prototype rainfall simulator was designed and tested in the laboratory to simulate rainfall at 100 $mm.h^{-1}$ intensity over different land management practices. The effect of five land management practices on runoff, infiltration and soil loss were evaluated for a set of rainfall intensity (100 $mm.h^{-1}$), rainfall duration (15 min) and raindrop size/ pore size of the nozzle (3.5 mm). The considered management practices were intense tillage land cover, zero or no-tillage land cover, minimum tillage land cover, perennial grass system and urban environment. Perennial grasses were found to be the best management practices to minimize the surface runoff and soil loss with increase in infiltration rate. Experimental results showed that perennial vegetation produced minimum runoff (0.2 l), very small soil loss (4.99 $kg.ha^{-1}$) and maximum infiltration rate (117.67 $mm.h^{-1}$), whereas urban environment (concrete surface) produced maximum runoff (3.7 l), minimum infiltration rate (0.1 $mm.h^{-1}$) and minimum sediment loss (0.08 $kg.ha^{-1}$).

Rainfall is a principal component of hydrologic cycle which effects the infiltration and runoff from a specific land use system. Soil surface plays a key role in the infiltration process, which is influenced by a variety of factors, including crusting, compaction and sealing at the soil surface, extent and type of vegetation cover, and surface topography (Bronstert *et al*., 2002). The influence of land uses on storm runoff generation is more complicated as land use and soil cover have an effect on interception, surface retention, evapotranspiration, and resistance to overland flow. For instance, cropland and urban land yield more flood volumes, higher peak discharges and shorter flow travel times than grassland or woodland. Increased runoff from the cropland is mainly due to the removal of native vegetation and soil compaction, which decrease soil infiltration capacity. Increased runoff from urban areas results from impervious surfaces that prevent infiltration of water into soils (Brun and Band, 2000). Urban land uses also reduce the surface roughness and, therefore, shorten the overland flow retention time.

Soil erosion due to surface runoff plays an important role in land degradation and desertification (Mueller *et al*., 2014; Karamesouti *et al*., 2015). Land cover and rainfall patterns (rainfall intensity and amount) are the two main factors that affect the runoff generation (Souchere *et al*., 2003; Yang *et al.,* 2003; Wei *et al*., 2007; Fang *et al*., 2012; Peng and Wang, 2012). Land cover, including living vegetation and litter, can significantly reduce the volume of surface runoff by increasing water infiltration into the soil (Grismer and Hogan, 2005; Smets *et al*., 2008; Shi *et al*., 2012). Understanding the effects of rainfall patterns and surface cover on runoff production helps in better soil and water conservation planning and management (Yu *et al*., 2016).

Rainfall simulators are primarily designed to replicate the natural rainfall process (Aksoy *et al*., 2012).These instruments generate a wide range of rainfall intensities as and when required in a controlled environment, and have been widely used for studying effect of rainfall on different hydrological processes such as runoff, erosion, and infiltration (Dunne *et al*., 1980; Abudi *et al*., 2012; Aksoy *et al*., 2012). Rainfall simulators are broadly classified in two types (a) drop-forming or non-pressurized nozzle rainfall simulators; and (b) pressurized nozzle rainfall simulators. In the drop forming rainfall simulators, droplets are generated through hypodermic needles, polyethylene tube and capillary tube (Chow and Harbaugh, 1965). A falling height of about 10–12 m is required to produce kinetic energies similar to those of natural raindrops. Pressurized nozzle rainfall simulators produce raindrops under applied pressure by using single or multiple nozzles. This type of rainfall simulator produces sufficient droplet velocities and kinetic energies at much lesser fall height (Aksoy *et al.*, 2012). There is no standard design of rainfall simulators, and their design depends on required rainfall intensity, drop size, droplet velocity kinetic energy, spatial rainfall distribution, and target area. The choice of a rainfall simulator is usually based on geometrical constraints, simplicity, portability, and costs.

Cornelis *et al*. (2004) constructed a wind tunnel and a rainfall simulator to study the effect of wind and rainfall characteristics on soil erosion. Arnaez *et al.* (2007) used a rainfall simulator to compare runoff and sediment production under distinct rainfall intensities in a vineyard plantation in Spain. Sheridan *et al*. (2008) used a simulator to obtain a modified erodibility index that could be used to predict annual erosion rates for forest roads. They used a rainfall simulator on 1.5 × 2.0 m plots, and carried out simulations for 30 min with an intensity of 100 $mm.h^{-1}$ and estimated kinetic energy of 0.295 $MJ.ha^{-1}.mm^{-1}$, which is similar to the kinetic energy of high intensity rainfall. Humphry *et al.* (2002) designed a new rainfall simulator which was easy to operate and transport while maintaining the intensity, distribution and energy characteristics of the natural rainfall. Neibling *et al.* (1981) presented the design for a modular programmable rainfall simulator that had a variable plot size and a wide range of rainfall intensities that could be programmed using a timer to change intensities during an event in fixed time steps. The rainfall simulators have the ability to take many measurements quickly without having to wait for natural rain and are also able to work with constant controlled rain, thereby eliminating the erratic and unpredictable variability of natural rain.

Surface cover is an important indicator of soil and water conservation, and is widely used to prevent soil and water losses on sloped lands (Reganold *et al.,* 1987; Rahma *et al.,* 2017). Field experiments conducted in the Chinese Loess Plateau under simulated rainfall condition to investigate the effect of rainfall intensity and vegetation (Caraganakorshinskii) cover on soil loss, sediment-associated nitrogen (N) and phosphorus (P) loss, and particle size distribution (PSD) of the eroded sediment revealed that vegetation cover, rainfall intensity, and their interaction all had significant effect on sediment and the associated N and P loss (Zhang *et al.,* 2011). Higher rainfall intensity and lower coverage produced higher sediment and consequently higher nutrient loss, but led to a lower enrichment ratio for N in sediments (Zhang *et al.,* 2011). Hurni *et al*. (2005) observed that there was 5 to 30 times more surface runoff from conventional tillage test plots than from forested or vegetated test plots. Fu *et al.* (2012) and Xie *et al.* (2015) concluded that rainfall intensity and quantity were the primary factors affecting subsurface flow generation based on rainfall simulations. Duan *et al.* (2017) studied the effect of different rainfall patterns on sloping Ferralsols under different land cover types (grass, litter cover and bare land) in the Jiangxi Provincial Soil and Water Conservation Ecological Park, and reported that the total runoff and surface flow were highest for bare land under all four rainfall patterns and lowest for the covered plots. They also observed that grass or litter covers are able to convert more surface flow into subsurface flow under different rainfall patterns. However, less attention has been paid in determining the effects of rainfall pattern under simulated conditions using different land management practises on runoff, soil loss and infiltration behaviour of clayey soils of Kashmir region under temperate climatic conditions.

In the present study, a pressurized-nozzle rainfall simulator was designed to study the effects of rainfall and land management practices on runoff, soil loss and infiltration behaviour of soil. The simulator used in the present study was small, portable having the capability to perform experiments on different surfaces with high repetition rates as well as ease of handling and control of test conditions. The main aim of the study was to identify the best land management practice for clayey soil under controlled condition, particularly when the erosion due to runoff poses a serious threat of land degradation.

## MATERIALS AND METHODS

### Design and Fabrication of Experimental Rainfall Simulator

The experiment was carried out at Soil and Water laboratory, College of Agriculture Engineering and Technology, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir (SKUAST-K) in 2016-2017.

The rainfall simulator consisted of soil holding trays, mild steel iron structure, water reservoir, sprinkle nozzle, pump, LDPE (Low Density Polyethylene) pipes, calibrated jars and outlets for infiltration and runoff (Figs. 1, 2). The dimensions of the MS angle (37.5 × 37.5 mm) frame for holding various components were 711.2 × 470 × 610 mm with rear leg height of 635 mm. A difference of 25 mm in heights of the front and rear legs resulted in 5% slope for the soil trays, so that different agronomical practices of growing vegetation on the selected mild sloping lands to cover them and to control the erosion as soil conservation practice could be examined. Two extended stands supported two calibrated jars, one right below the runoff conduits and the other below the infiltration outlet. These transparent calibrated plastic jars were used for collection of runoff and infiltration water from the trays. The jar was calibrated in millilitres (ml), with least count of 5 ml and volumetric capacity of 1000 ml. Considering the weight of the soil trays, the frame was designed to hold only two trays at a time, and next trays were used when the experiment on the first two trays was completed. Water from a reservoir (20 l capacity) was pumped with a submersible fountain

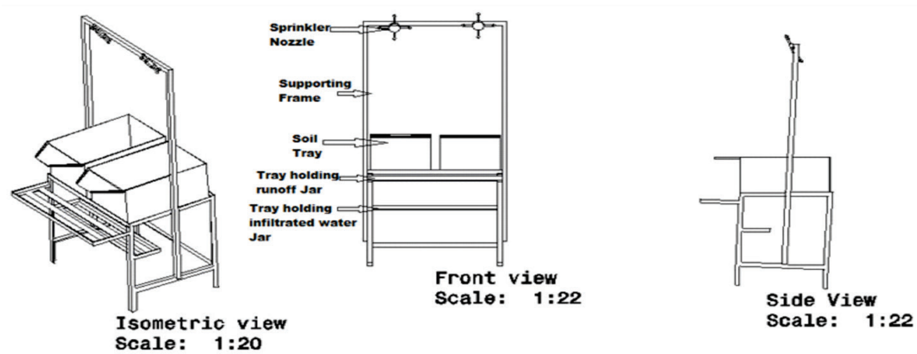


**Fig. 1: Schematic diagram of rainfall simulator**

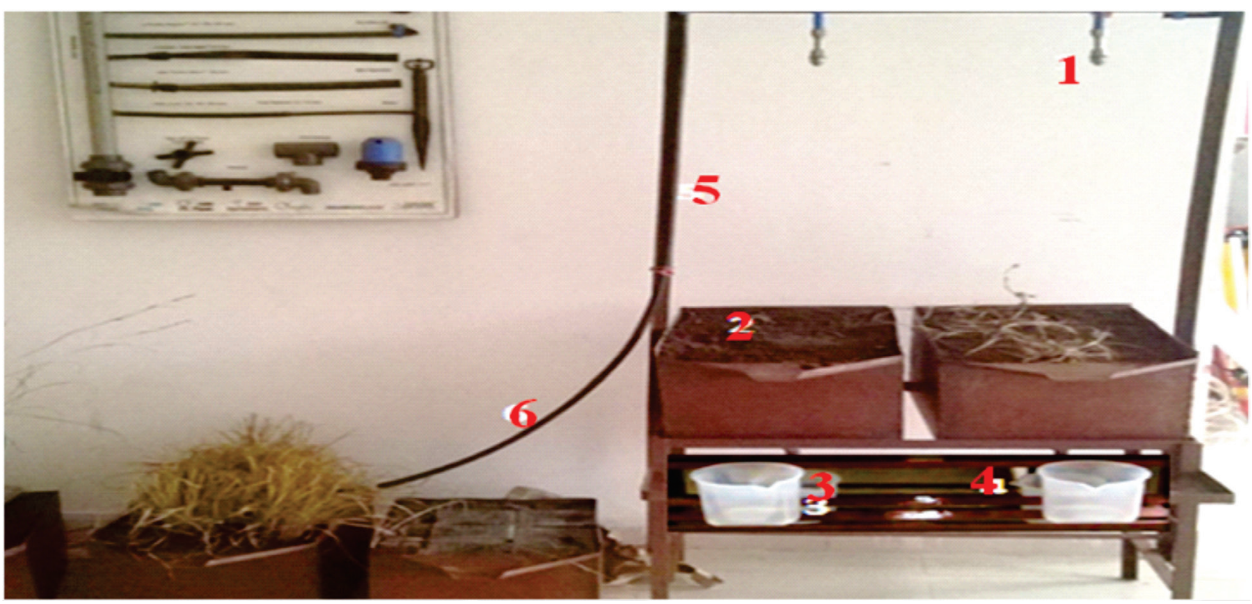


**Fig. 2: Various components of rainfall simulator: (1) Sprinkler nozzle, (2) Soil surface land management practice, (3) Jar for collecting runoff from soil holding trays, (4) Outlet to collect infiltrated water, (5) Supporting frame, and (6) Water supply pipe connected to a reservoir through pump**

pump, working on alternating current of 180-240 V, power supply of 20 W, maximum head of 1.85 m. LDPE pipes (16 mm diameter) were used to convey water from the reservoir to the Vee Jet series sprinkler nozzles of diameter 3.5 mm to create an artificial rainfall onto the soil holding trays. The dimensions of the soil trays were designed on the basis of infiltration depth of soil. The soil holding trays were of 469×254×315 mm in dimensions with 0.12 $m^2$ surface area and 37.6 l volume. A hole of 25 mm diameter on bottom of each tray was provided to collect infiltrated water. The hole was fitted with a local plumber conduit (Fig. 1). Mild steel sheets were used for construction of trays. The trays were painted with lead oxide for protection from rusting. Each tray had a trapezoidal weir outlet for collection of runoff and measurement of the height of water in the weir calibrated to determine the runoff discharge rate. The weir was placed at the front side of the cuboid protruding almost 125 mm in perpendicular distance away from the edge.

The trays were filled with clay soil (*Gurti soil*) which was obtained from the vicinity of College of Agriculture Engineering and Technology, SKUAST-K. The characteristics of the soil used for the experimentation are given in Table 1. The soil used in the trays was clay soil (clay, silt and sand in the ratio of 46.0 %, 43.8 % and 10.2 %) having particle density, bulk density and organic carbon matter $2.70\times10^3$ $kg.m^{-3}$, $1.52\times10^3$ $kg.m^{-3}$ and 0.92 %, respectively (Table 1). The pH and EC of the soil were 6.05 and 0.06 $dS.m^{-1}$, respectively. The saturated hydraulic conductivity as measured with Guelph permeameter (Zhang *et al.,* 1998) was 18.5 $mm.h^{-1}$. The soil depth in the trays was fixed at 265 mm with a freeboard of 50 mm to withstand the splash effect of simulated rainfall. A nozzle was placed at a height of 0.75 m from the ground to provide a natural free fall condition for rain drop,distributed over the entire surface of the soil present in a tray. The discharge rate of the nozzle was controlled by using a bypass valve in the supply line, and a discharge rate of $4.16\times 10^{-6}$ $m^3.s^{-1}$ over an area of 0.045 $m^2$ with a rainfall intensity of 100 $mm.h^{-1}$ was used in this study.

**Table 1. Characteristics of soil used for study**

| Sl. No. | Soil property | Value |
|---|---|---|
| 1. | Soil depth, mm | 265 |
| 2. | Texture<br>Clay,%<br>Silt,%<br>sand,% | <br>46<br>43.82<br>10.18 |
| 3. | Bulk density, $kg.m^{-3}$ | $1.52\times10^3$ |
| 4. | Particle density, $kg.m^{-3}$ | $2.70\times10^3$ |
| 5. | Saturated hydraulic conductivity, $m.s^{-1}$ | $5.13\times10^{-6}$ |
| 6. | Field capacity,% | 36 |
| 7. | Porosity, % | 44 |
| 8. | Soil pH | 6.05 |
| 9. | Electrical conductivity, $dS.m^{-1}$ | 0.06 |

### Selection of Soil and Land Management Practices

Different land covers namely, intense tillage land cover, zero or no tillage land cover, minimum tillage land cover, perennial grass system and urban environment land cover were used for quantifying runoff, infiltration rate and soil loss under simulated rainfall conditions. Intense tillage land cover disturbs the entire soil surface and is performed prior to and/ or during planting (Fig. 3a), and thereby leaving the soil bare without any vegetation cover. Zero or no tillage land cover is represented compact the top soil without any vegetation, and consequently reduce the storage capacity or the rate of water infiltration (Fig. 3b). Minimum tillage land cover does not involve soil inversion and maintains a high level of surface residue (Fig. 3c). This soil management system had 30 % residue cover. The conditions of minimum land cover were imitated by observing the actual field conditions as observed under minimum tillage conditions.

Perennial grass system was imitated by planting perennial grasses slips (*Dactylis glomerrata*) for 45 - 50 days in the tray, with grass density of 0.001 kg. $m^{-2}$ (Fig. 3d). Under urban environment, two different options of (a) concrete land cover and (b) asphalt bricks cover were used [Fig. 3(e, f)]. The concrete land cover was imitated by using an impervious hard cardboard layer that was stiff enough to withstand the impact of rainfall. In case of the asphalt brick cover,asphalt bricks of 30 mm thickness were laid in the soil tray, covering the entire surface of the soil in the tray.

### Simulation of Rainwater

The discharge rate of the nozzles was maintained at $4.16 \times 10^{-6}$ $m^3.s^{-1}$, over an area of 0.045 $m^2$ of soil tray under different land management practices with a rainfall intensity of 100 $mm.h^{-1}$. The simulated rainwater was collected in the soil system present in the tray. Some of the rainwater flowed as runoff, and some infiltrated into the soil to finally moves out as

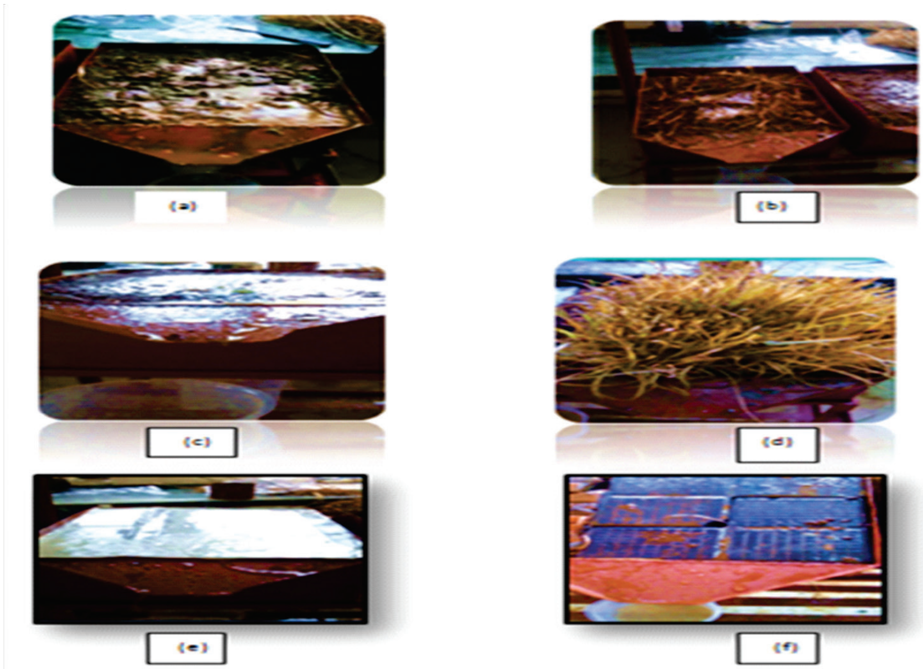


**Fig. 3: Simulations of different land management practices: (a) Intensively tilled system, (b) Minimum tilled system, (c) No tilled system, (d) Perennial vegetation system, (e) Concrete land cover, and (f) Asphalt bricks**

infiltrated water. The amount of water flowing out as runoff and infiltrated water depends on soil properties as well as land cover. The runoff and infiltrated water were independently collected in the calibrated jars. The data were used to compute soil loss, runoff and infiltrated water. Soil samples were collected from the jars for computation of soil loss from different soil trays.

### Design of Experiment

The dynamics of rainfall-runoff process depends on the type of soil cover to a large extent, and the different land covers used in this research included intensely tilled soil system, minimum tilled soil system, a no-tilled soil system, a perennial vegetation cover and impervious surface representing urban areas. The land management practices (intense tillage land cover, zero or no-tillage land cover, minimum tillage land cover, perennial grass system and urban environment) were applied on clayey soil obtained from the fields in vicinity of the College of Agricultural Engineering and Technology, SKUAST-K. The effect of land management practices on dependent parameters like runoff, infiltration and soil loss were evaluated for using a set of independent parameters viz. rainfall intensity 100 $mm.h^{-1}$, rainfall duration 15 min and raindrop size/pore size of 3.5 mm of the nozzle. The experiment was repeated five times for two trays at a time with two different management practices, and the average values of runoff, infiltration and sediment yield were taken. Hence, the experiment was repeated fifteen times for six trays with six different management practices.

## RESULTS AND DISCUSSION

### Impact of Rainfall on Land Management Practices

The impact of five land management practices in combination with rainfall intensity (100 $mm.h^{-1}$), rainfall duration (15 min) and raindrop size/pore size of the nozzle (3.5 mm) on runoff, infiltration and soil loss were evaluated in this study. The results of experimentation on amount of runoff, infiltration and sediment yield under different land management practices simulated by rainfall simulator is presented in Table 2.

### Intensive tilled, minimum tilled, no-tilled soil system

The runoff amount and infiltration in intensively tilled soils were 83 % and 17 % of simulated rainfall, respectively, and the soil loss was 53331.2 $kg.ha^{-1}$ (Table 2). In case of minimum tilled soil system, runoff and infiltration were 70 % and 30 %, respectively, of the incident rainfall. Soil loss was 26665.6 $kg.ha^{-1}$, almost half of the soil loss occurring in intensely

**Table 2. Dependence of runoff, infiltration and sediment yield on different land management practices under certain controlled conditions**

| Sl. No. | Subject | Land use system | Runoff, | | Infiltration, | | Soil loss, |
|---|---|---|---|---|---|---|---|
| | | | l | % of rainfall | $mm.h^{-1}$ | % of rainfall | $kg.ha^{-1}$ |
| 1. | Intensely tilled soil cover | Very loose, without vegetation | 3.1 | 83 | 21 | 17 | 53331.2 |
| 2. | Minimum till soil system | 30% residue cover on the surface | 2.62 | 70 | 37 | 30 | 26665.6 |
| 3. | No-till soil system | Hard upper layer, without vegetation | 3.45 | 92 | 10 | 8 | 17499.3 |
| 4. | Perennial vegetation | Vegetative cover | 0.2 | 4 | 117.67 | 96 | 4.99 |
| 5. | Urban environment | a. Concrete surface | 3.7 | 99 | 0.1 | 0.1 | 0.08 |
| | | b. Asphalt bricks | 2.86 | 77 | 29 | 23 | 5.83 |

tilled soil cover. This was mainly due to the fact that minimum tilled soil cover bore the plant residue cover that hindered the flow and broke the flow pathway of the runoff, thereby giving the rainwater an extra ponding time to seep into the soil profile. Aksoy *et al*. (2012) also reported maximum runoff and soil loss under extensively tilled soils while studying the effect of different intensities, spatial uniformity, raindrop size, velocity and kinetic energy on different land covers. They also reported that minimum tilled soil resulted in slightly increased infiltration, reduced runoff and soil loss as compared to tilled soils. Under no-tilled soil condition, the runoff and infiltration were 92 % and 8 % of the incident rainfall, respectively, with soil loss of 17499.3 $kg.ha^{-1}$. The reason of higher runoff was that no vegetation existed and the soil surface acted similar to a hard surface.

### Perennial vegetation system

Amongst all the land cover treatment considered, the perennial vegetation system resulted in minimum runoff (4 % of rainfall) and maximum infiltration (96 % of rainfall), and the soil loss was also low (4.99 $kg.ha^{-1}$). In this land management practice, the canopy of the vegetation acted as a filter to reduce erosion and runoff, and improved the infiltration. The volume of runoff generated from perennial vegetation system was almost 15 times less than that of the conventional intense tillage system with a subsequent increase in the amount of water infiltration. This might be due to the fact that in perennial vegetation system, the canopy of the vegetation intercepted the falling rainfall and reduced the impact of raindrop on soil surface, and acted as a filter to reduce runoff, sediment yield and increase the infiltration capacity of soil. While studying the effect of slope and grass cover on infiltration rate, run-off and sediment yield under simulated rainfall conditions, Joshi (2013) observed that grass cover is the most effective measure in inducing infiltration and in turn minimizing run-off and sediment yield.

### Urban environment

Under urban environment condition, concrete sheet and asphalt bricks resulted in higher runoff, lower infiltration and soil loss. Concrete sheet resulted in maximum runoff (99 % of rainfall), minimum infiltration (1 % of rainfall) and minimum soil loss (0.08 $kg.ha^{-1}$). Asphalt brick surface yielded 77 % of rainfall as runoff and 23 % of rainfall as infiltration, with soil loss of 5.83 $kg.ha^{-1}$. The asphalt brick layer had 7.5 mm gap between two bricks, which enhanced the infiltration rate. The difference in infiltration and runoff in case of concrete cover and asphalt bricks was mainly due to infiltration in case of asphalt brick cover due to the gap between two bricks. Mandal *et al*. (2005) using a portable rainfall simulator in semi-arid tropical India reported that rough surface like stones enhanced infiltration, and protected the soil against erosion. They reported infiltration in the range of 26 % to 83 % of rainfall, and soil loss rate less than 2 $t.ha^{-1}$ for a field with stone cover of 64.7 % even when the rainfall intensity was increased to 136.8 $mm.h^{-1}$.

## CONCLUSIONS

In the present laboratory study, simulated rainfall event of 3.5 mm rain drop size at 100 $mm.h^{-1}$ intensity for 15 minute duration indicated that perennial grass cover was the best management practice to minimize the surface runoff (4 % of rainfall) with negligible soil loss (4.99 kg.ha$^{-1}$) and increasing potential groundwater recharge. The volume of runoff generated from perennial vegetation system was almost 15 times less than that of the conventional intense tillage system with a subsequent increase in the amount of water infiltration. Maximum sediment yield (53331.2 kg.ha$^{-1}$) occurred in intensely tilled soil cover because of loose soil particles getting easily detached by impact of raindrop. Minimum sediment yield was observed with concrete surface (0.08 kg.ha$^{-1}$). Asphalt bricks with gap ranging from 7-15 mm between two bricks tend to enhance the infiltration rate under urban environment conditions resulting in higher infiltration rate as compared to concrete surface.

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