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The role of rainfall and light interception by litter on maintenance of surface soil water content in an arid rangeland (Khabr National Park, southeast of Iran)

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Abstract

The impact of rainfall and light interception by litter on maintenance of surface soil water content is determined in an arid rangeland in Khabr National Park in south-east of Iran. Litter weight sampling is done by 90 square plots, each 1 m^2, that are randomly placed within site. After determining the intensity of a typical storm of the region (20 mm/h), the rainfall duration required to saturate the litter from dry-weight to constant-weight is determined from the litter wetting curve. To plot the wetting curve, an outdoor rainfall simulator is used to wet the litter. Then drying curve of litter moisture content is determined from obtained field data with four replications. For measuring soil water content, three treatments are tested i.e. bare soil, soil with wetted litter and soil with dry litter. Average of the measured interception loss of four samples was 0.64% of this specific simulated rainfall (5.2 mm). This study clearly showed that rangeland litter decrease evaporation of the soil water content and light interception by litter have more important role in decreasing evaporation from the soil water content than the rainfall interception by litter.

Keywords: Litter interception; Light interception; Evaporation; Soil water content; Arid rangeland

1. Introduction

Litter refers to all dead (standing or fallen) plant material above the soil surface (Naeth, 1988). In this study, litter is defined as the recognizable dead plant residue on the soil surface. Litter is an important component of the majority of plant communities (Facelli and Pickett, 1991) that performs several important functions in ecosystems. Litter maintains nutrient and energy flow at the soil–plant interface, provides habitat for various soil organisms and protects soil from erosion (Sangha *et al.*, 2006). Plant litter helps conserve soil moisture by reducing soil temperature and evaporation (Weaver and Rowland 1952, Hopkins 1954). Snyman (1998) states that the largest percentage of soil drying immediately after wetting, in semi-arid areas, can be ascribed to evaporation from the soil surface. Litter conserves soil moisture by reducing evaporation from the soil but reduces input from rainfall by interception water equivalent to about twice the weight of litter (Naeth *et al.*, 1991).

Understanding hydrological characteristics of the rangeland ecosystems is essential (Wiegand *et al.*, 2004). One of the important components of

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the rangeland ecosystems is Litter. Water balance processes in the litter layer are important in litter decomposition and nutrient movement. Hence it is necessary that this be dealt with in hydrologic models of an ecosystem (Waring *et al*., 1980).Litter interception loss is rainfall retained in the litter layer and evaporated without adding to moisture in the underlying mineral soil (Hamilton and Rowe, 1949).

There have been several studies of litter water balance, According to Helvey and Patric (1965), 2 to 5% of the annual rainfall in the southern Appalachians is intercepted by Hardwood litter. Helvey and Patric (1965) expressed two methods for measuring litter interception loss. These methods were called by Gerrits *et al*. (2006) as lab method and field method:

1. Lab methods, whereby field samples are taken to the lab and successively the wetting and drying curves are determined by measuring the moisture content.
2. Field methods, whereby the forest floor is captured into trays or where sheets are placed underneath the forest floor.

Evaporation from litter interception is calculated to be 34% of the throughfall in the beech forest in Luxembourg by them that is quite high compared to the literature. Corbett and Crouse (1968) measured the litter interception loss by applying the 32 years of rainfall data to regression equations and found that averaged 4.3% annual rainfall evaporated from a grass litter. In juniper communities, 5% of the precipitation is intercepted by litter and duff beneath the tree and evaporated back to the atmosphere (Owens and Lyons, 2004). Thurow *et al*. (1987) found average Litter interception of 20.7% Annual Rainfall for live Oak (*Quercus virginiana*).

During a storm, water falling on the litter will gradually increase the litter moisture level to field capacity. Additional water will then percolate through to the bottom of the litter and infiltrate into the soil unless the capacity of the soil to absorb water is exceeded. Then additional rainfall could raise the litter moisture to saturation (Warring *et al*., 1980). The evaporation of the soil moisture content can be replaced with moisture that retained in litter.

In arid and semi-arid rangelands, as soil and plant processes are controlled by rainfall (Ludwig and Tongway, 1998; Ingram, 2002), one of the most important principles in sustainable utilization of these areas is efficient soil–water management (Snyman, 1998; Oesterheld *et al*., 2001). Litter conserves moisture by reducing evaporation making scarce moisture more effective (Adams *et al*., 2005).Thus management for litter accumulation may be as important as management for increasing live plant material cover for hydrologic benefit on most rangelands (Branson, 1984).

After a storm, litter maintains moisture in the soil by various ways. Two of these ways are light and rainfall interception of litter. Light interception refers to the litter role in protecting soil from sun radiation. It means that litter stops most of the incoming radiation and reduces soil evaporation (Kelliher *et al*., 1986; Schaap and Bouten, 1997; Ogée *et al*., 2001). Furthermore evaporation of surface soil moisture can be replaced by moisture evaporation of litter (rainfall interception of litter), but there are no studies available about the role of rainfall interception of litter on reducing soil evaporation. In the past these ways were largely investigated together as one process, but in this study the role of these two ways are separated. The objectives of this study are therefore to determine the amount of litter interception loss in a shrubland and its effect on stabilization of surface soil water content.

2. Materials and methods

2.1. Study area

The study site is located in Khabr National Park in the Kerman province in south-east of Iran (28º53’58”N, 56º25’02” W). This area is characterized by 312.7 mm mean annual precipitation, and 17.6ºC mean annual temperature. Precipitation mostly occurs in winter and spring, falling as rain and snow. Soils are Entisols with low degree of development which are sensitive to erosion. Soils in the study area are mostly loams. The elevation of the site study ranges from 2050 to 2200 meter above sea level. The absolute maximum and minimum mean temperature of the hottest and coolest month are 39.5 and -5.6ºC respectively. According to Emberger method, region climate is arid frigid. According to the Gaussen’s ombrothermic diagram, aridity period is 7 months in the region.

The study area is steppe, and vegetation of study area is dominated by *Artemisia sieberi* (Besser) and *Stipa barbata* (Desf.) (Fig. 1).

Fig. 1. A shrub steppe of Khaber National Park with dominant species of *Artemisia sieberi* (Besser) and *Stipa barbata* (Desf.)

2.2. Measuring litter weight

For obtaining accurate estimate of litter weight, a preliminary sampling is done by 12 square plots that each plot was 1 m^2. By using calculated litter variation and selected the desired accuracy of estimation, numbers of required samples (plots) to be computed from following equation:

$$n = t^2 s^2 / d^2 \qquad (1)$$

in this equation n is the number of samples, t is taken from a t-table for the desired confidence level and the degrees of freedom, s^2 is estimated variance of the population, and d is the desired difference between sample and population mean.

According to this equation, the numbers of required samples (plots) are calculated 90 samples. These 90 plots are randomly located within study area. In each plot, the litter area is estimated and the whole litter mass is collected for weighting. For preparing drying and wetting curves, according to the estimated litter area several sampling plots were made (0.15 m^2 quadrat) which had permeable bottom of metal nets. The collected litter is uniformly distributed on the entire wooden plots without changing normal thickness of the litter in the area Therefore the plots are completely covered by litter (100% coverage) for simulating the rainfall.

2.3. Measuring litter interception loss

To choose the intensity of a typical storm as a representative for the study site, the long records of rainfall of the region was studied. Eventually, a 60 mm rainfall happening within 3 hours was chosen as the typical storm with the intensity of 20 mm/h. An outdoor rainfall simulator was used for generating this intensity.

The rain duration, the time required for litter to reach from minimum to maximum water content, was determined from wetting curve. Actually this curve indicated that how much rainfall required to saturate litter. Preparing litter wetting curve is completed step to step. At the first step, rainfall simulation is done for 5 minutes. At the other next steps, rain duration is extended for 5 minutes more than its previous step. After each step of rain simulation, the plot covered to prevent evaporation and to permit excess water to drain into soil. After 1 hour draining, the plot is weighted to determine water content which is the potential moisture available for evaporation.

Drying curve is inverse of wetting curve. Drying curve indicates the time required for litter to dry from maximum to minimum water content. For preparing this curve, rain simulation is carried out for 40 minutes that is calculated from wetting curve. Immediately after rainfall simulation, the samples are covered by plastic sheet to prevent evaporation and to permit the excess water to drain in to underlying soil. After 1 hour draining the sample is weighted. Weighting of sample is repeated at next days at same time until the sample weight reaches to a constant weight.

The difference between starting and ending moisture content gives the evaporated water in g/m^2. Moisture content at the beginning and the end of drying litter is determined from drying curve (Helvey, 1964). Field capacity is the water content (percent by weight) of litter 1 day after rain (Blow, 1955).

2.4. Measuring soil water content

A gravimetric technique was used for measuring soil water content. Three plots are used for sampling that each plot is 1 m^2. The first plot includes bare soil, the second and third plots include soil that covered by litter. Rainfall is simulated on these three plots for the duration that acquired from wetting curve (40 minutes). After 1 hour draining, soil samples are taken from the first 5 cm of the top soil of the plots and wetted litter on the third plot is replaced with dry litter. Sampling is carried on at the next days at the same times until water content of bare soil reaches to a minimum. In each sampling, four replications are randomly distributed over the plots. Thus, here three treatments are tested: 1- bare soil, 2- soil covered by litter and 3- soil covered by litter that after saturating litter, its wetted litter is replaced by dry litter.

2.5. Uncertainty analysis

To determine the margin of uncertainty of each measured point, mean of estimates (*m*) and their standard deviation (*s*) are calculated. Then the 95% confidence intervals are used as a measure of uncertainty. The significant intervals for each point are obtained as $m \pm t_{a,n}s$, where $t_{a,n}$ is student's t-distribution, with probability α and n degree of freedom. α usaully 0.025 is chosen, so that each point is contained in the confidence interval with a probability of $1- 2\alpha$, i. e. 95%. For that t-student test is applied. Later in the next section, margin of uncertainty of each estimate is shown as a band over the points of the soil moisture drying curves (Fig. 5).

3. Result and discussion

The mean litter weights in this region is calculated 83.5 g/m^2 and the mean litter areas is estimated 15% (1500 cm^2/m^2). Therefore the area of each plot is 1500 cm^2 that uniformly filled with 83.5 g litter and the rain is simulated for these plots. The amount of litter is significantly lower than the amount of litter in forest Reported litter production in hardwood stands in eastern united states ranges from 269 to 493 g/m^2 (Blow, 1955; Sims, 1932). Litter accumulation in eastern Tennessee ranged from 448 to 2690 g/m^2, depending on stand composition and history (Blow, 1955). The average annual litter accumulation for the chaparral types found on the San Dimas Experimental Forest ranged from 46.96 to 457 g/m^2. The average annual accumulation was 148.3 g/m^2 (Kittredge, 1939). According to Ekaya and Kinyamario (2001), Monthly litter production in an arid rangeland in Kenya ranged from 31.4 g/m^2 to 130.0 g/m^2 and mean monthly yield was 92.5 ± 26 g/m^2, with a 28% coefficient of variation. Litter biomass was of the order of 130 g/m^2 in Astrebla grasslands, 160 g/m^{2}in open woodlands and 400 g/m^2 in Acacia scrublands (Friedel, 1981).

In figure 2 wetting curve of litter is given. Water content of litter is indicated in this curve for rain simulation with 5 minutes to 60 minutes duration. In this curve water content of litter progressively increased until litter weight became constant at the rain simulation with 40 minute duration. It was concluded that the rain simulation with 40 minute duration could saturate litter and it was applied for experimental plots.

In figure 3 drying curve is presented. According to this curve, more than half the evaporative loss occurs within 5 days after rain simulation and that little amount of water loss occurs after 9 days of drying.

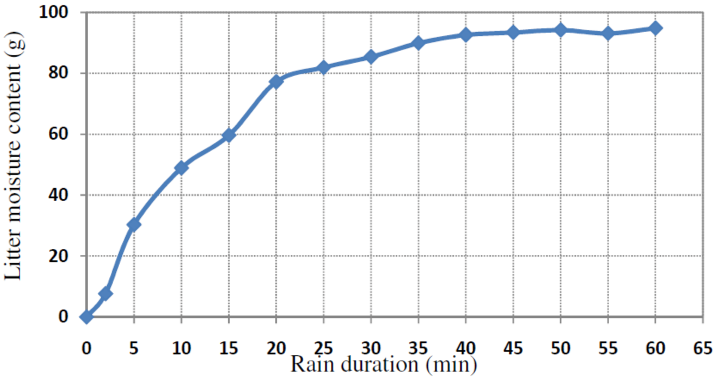

Fig. 2. Moisture content of litter after rain simulation with different durations

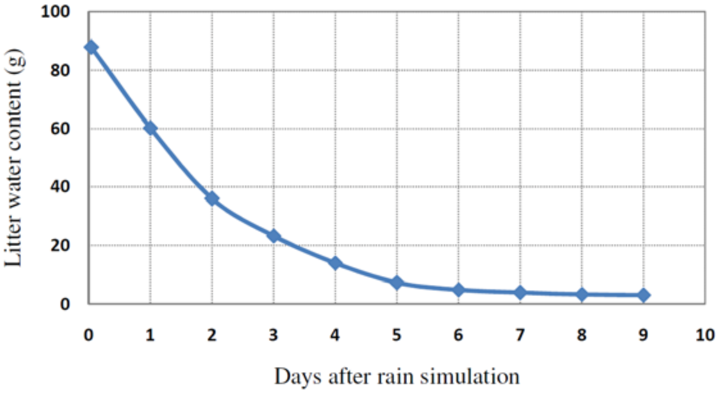

Fig. 3. Changes in evaporated water for each day after rain simulation

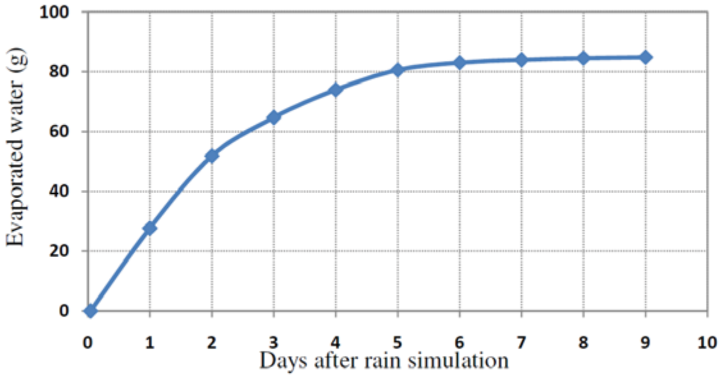

Fig. 4. Total evaporated water for each day after rain simulation

The maximum weight of moisture is reached at about 106% of the litter weight. The minimum water content is close to 3.5% of the litter weight. The measured field capacity was about 43% by weight. Also these results could be obtained from cumulative evaporated water curve that is presented in figure 4. It was calculated that 0.64% (equal to 5.2 mm) of the simulated rainfall is evaporated from litter in the shrub steppes of Iran.

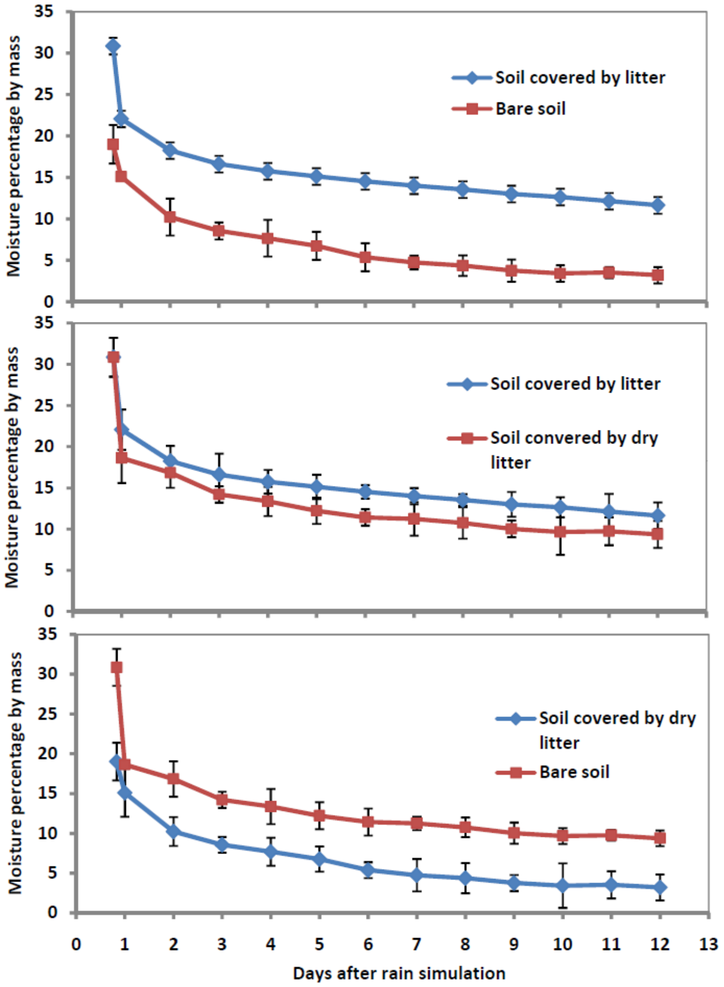

Fig. 5. Soil water content (%), measured every day after rain simulation, over 5 cm depth for different soils, each point is illustrated with 95% confidence intervals

The water content for the different soils is presented in figure 5. For better comparison of the water content of different soils, these curves are presented as pair. The drying curves of bare soil and soil covered by wetted litter are plotted in figure 5(a). This figure shows that drying rate is clearly faster in soil with the wetted litter than in the bare soil. Thus litter significantly can reduce evaporation of surface soil moisture. This role of litter could refer to light and rainfall interception. For separating the roles of light and rainfall interception of litter in surface soil moisture maintenance, soil moisture drying curve of soil covered by wetted litter with soil covered by dry litter, and soil covered by dry litter with bare soil are plotted in figures 5(b) and 5(c). The role of rainfall interception of litter in soil moisture conservation is presented in figure 5(b). According to this figure evaporation of litter moisture has no significant role in reduction of drying rate of underlying soil. Figure 5(c) highlights the role of light interception of litter in conserving underlying soil moisture. Regardless to the second day, light interception of litter significantly reduces the drying rate of underlying soil. Therefore the role of litter in surface soil moisture protection is mostly related to its role in intercepting sun radiation than its role in intercepting rainfall.

4. Conclusion

The litter weight in this shrub steppe (83.5 g/m^2) in comparison with other reports appears to be reasonable. Amount of interception loss in shrub steppes in Iran is 0.64% of the simulated rainfall (5.2 mm). Thus, it can concluded that litter interception have a rather significant role on arid and semi arid rangeland water budget.

This study clearly showed that rangeland litter decrease evaporation from the soil water content and, light interception of litter have more important role in decreasing evaporation of the soil water content than rainfall interception of litter. Litter has a positive impact on surface soil water content and maintains moisture in the soil for longer periods after rainfall. The amount of solar energy for evaporation and transpiration is constant for any time and place, so evaporation of intercepted moisture by litter simply replaces the soil surface evaporation that would have occurred in the absence of litter. Thus it may be concluded that the role of litter interception in reducing the input (precipitation) to the basin hydrological cycle is compensated by its soil moisture conservative role. The results obtained in this study can be a reason for litter maintenance for its conservative roles on the soil water content in arid and semi arid rangelands there rainfall is the most important limiting environmental factor. With regarding amount of litter on rangeland, amount of water intercepted by litter and its role on conservation of moisture and temperature of soil surface, it can concluded that one of the important factors in rangeland function is litter and its rainfall interception, so litter as a fertile patch with significant role in rangeland hydrology and soil moisture regulation should be studied more.

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