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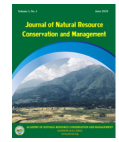

Aggregate breakdown of two texturally different soils under different land-uses in semiarid tropical environments

M.S. Hadda and Balbir Singh

Department of Soil Science, Punjab Agricultural University, Ludhiana-141004, Punjab, India
**Corresponding author: ms_hadda@yahoo.com*

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ABSTRACT

The aggregate breakdown phenomenon under a land-use differs with changes in rainfall characteristics and aggregate size. Therefore, an attempt has been made through the present study to evaluate the aggregate breakdown dynamics using 4-land-uses, 4- aggregate size classes, and 3- moisture contents following a completely Randomized Block Design using a simulated single raindrop technique. The natural aggregates were collected from two texturally different soils that is, sandy loam and loamy sand at DR Bhumbla Zonal Research Station for Kandi Area, Ballowal–Saunkhri, district SBS Nagar, Punjab. These different sized aggregates were exposed to simulated single raindrops of size 2.5, 3.5, and 4.5 mm respectively. Each sized aggregate breakdown by a single raindrop technique under a land-use follows the order: fallow>arable>forests>grasses. The kinetic energy of raindrop at impact was higher under land-use grasses at air-dry moisture content and minimum under land-use fallow at saturated moisture content in both types of soils. The interactive effect of land-use and aggregate size was significant in breakdown of the aggregate at known moisture content by a single raindrop technique. Further studies are needed to quantify the potential effects of plant root systems in breakdown of aggregate under a land-use.

Keywords: Raindrop size, moisture content, kinetic energy, aggregate size

INTRODUCTION

Soil erosion by water is the major cause of land degradation in submontane Punjab. This region lies in the foothills of Shivalik, which is one of the most degrading parts of the Himalayan ecosystem. The area suffers from the serious menace of water erosion due to indiscriminate human interference, undulating topography, climatic hazards, poor soil structure, and high erodibility of soils (Kukal et al., 1991; Hadda et al., 2001; 2002). However, the important aspect of erosion control lies in understanding the process of erosion in the region which is often neglected while deciding on various soil conservation strategies.

Soil aggregates are formed by the association of clay particles into domains, silt particles into micro-aggregate and micro-aggregate, and sand particles into aggregates (Greenland, 1977). These aggregates occur in the form of peds, clods, fragments, or concretion. Aggregate stability influences several aspects of a soil's physical behaviour, mostly water infiltration, and erosion. However, soil surface sealing results in decreased infiltration and increased overland flow and erosion. In addition, the relationship between crusting and erosion was investigated by Hairsine and Hook (1994), these two erosion processes were controlled to a great extent by aggregate breakdown processes. Whereas, soils' response to this shear stress depends upon their mechanical makeup and chemical composition. All other factors remain the same; differences in erosion up to 30-folds have been observed due to differences in their composition and soil properties (Olson and Wischmeier, 1963). This may be attributed due to soil erodibility, which is defined as a complex inherent property of the soils due to which different soils get eroded at different rates despite the same intensity of erosive agent. Thus, soil erodibility plays an important role in erosion prediction and planning suitable soil conservation measures.

Further soil property-based indices are site specific and cannot be used for other places. Therefore, aggregate stability measurements combine and integrate the effect of all the textural and chemical parameters with their interactions in a single value. However, the relationship between aggregate stability and erosion has generally been dealt with at an empirical level without considering the different aggregate breakdown processes that occur under specific conditions (Fox and Le Bissonnais, 1998). This explained why positive correlations between aggregate stability and soil erodibility (Coose et al., 1988), as well as negative correlations, have been reported in the literature (Bajracharya and Lal, 1992).

However, to measure aggregate stability, Le Bissonnais (1996) proposed a method consisting of three treatments that differentiate various mechanisms of breakdown: Slaking due to fast wetting (Treatment I), micro-cracking due to slow wetting (Treatment II), and mechanical breakdown by stirring of pre-wetted aggregates (Treatment III).

However, no evidence is available in the area that demonstrated an aggregate breakdown under different land-uses with texturally different soils. But few studies (Kukal et al., 1991; Kahlon and Khera, 2000) have been undertaken to evaluate soil erodibility under different land-uses in the area. The studies carried out are either based on applying simulated rainfall on the disturbed soils (Kahlon and Khera, 2000) or on exploiting various chemical and physical properties of soils in terms of erodibility indices (Kukal et al., 1991).

The soil parameters, except aggregation-based indices, have been proven to be unsuccessful in evaluating soil erodibility for a place (Bryan, 1968, Lindsay and Gumbs, 1982). Even the indices based on an aggregation of soils in terms of water stability do not simulate the actual energy situation that the soil aggregates face through falling raindrops. Thereby the soil aggregates which become water-stable by the gentle slaking action of wet sieving may not be remaining water stable when subjected to high-intensity rainfall (Bryan, 1968). As the aggregate's stability under raindrop impact is a property that is correlated with erodibility to the highest extent (Young and Onstad, 1982, Albuquerque et al., 2000), the same can be suitably exploited to evaluate erodibility. Therefore, a single raindrop technique (Bruce-Okine and Lal, 1975) can be used to determine the erodibility of soils in-situ under the direct impact of raindrops on a single aggregate. However, this technique can evaluate the erodibility quite close to actual conditions apart from being simple, rapid, and inexpensive. Keeping these points in view, the present investigation was undertaken to understand the aggregate breakdown of two texturally different soils under different land uses in semiarid tropical environments.

MATERIALS AND METHODS

Description of the area

The present study was carried out with soil samples and aggregates collected from different land uses at DR Bhumbla Zonal Research station for Kandi Area, Ballowal- Saunkhri, located in district SBS Nagar, Punjab. The study area comprised land uses such as fallow, forest, grasses, and arable (Maize –Wheat). It is situated at an altitude of 355 m above the mean sea level, having a semiarid to sub-humid type of climate as per the classification of Thornthwaite (1948). It is situated in agro-climatic zone-I of the Punjab state. Geologically, the area forms the southern part of the Shivalik ecosystem which lies between 30°40' to 32°30' N latitude and 75°30' to 76°48' E longitude.

Climate

The mean annual rainfall of the area is 850 ± 150 mm. Of the total rainfall, more than 80% is received in the summer monsoon months (July to September) and the remaining 20% in the winter months (October to March). The summer monsoon rains are received in 20 to 30 rainstorms, of which 8 to 12 produce runoff and overland flow (Hadda and Sur, 1986). These high-intensity rainstorms, though concentrated for a short period play a major role in physically degrading the soils (Lal, 1992). A higher coefficient of variation is observed in winter rains compared to summer monsoon rains in the area. This suggested that the winter rains are more erratic in nature and uncertain. The mean maximum temperatures vary from 18.6°C in January to 39.1°C in May and the mean minimum temperature varies from 5.2°C in December to 24.7°C in June. Due to high intensity and short-duration rainstorms, the soil loss varied from 25-225 tons/ha/yr on a small to large watershed in the area (Hadda and Sur, 1986).

Soils

Most of the soils range from loamy sand to sand in texture and possess low to medium moisture retention capacity. These soils are highly erodible. About 68% of the soils have erodibility values greater than 0.40. Of these, 6% of the soils have values greater than 0.6 (Kukal et al., 1991). The soils of the area are represented by the great groups of Haplustepts, Ustorthents, Ustipsamments, and Haplustalfs (Kumar et al., 1995). Marginal lands consist of stream-affected areas, steep slopes, highly eroded soils, and excessively permeable and less water retentive soils. Most of these marginal lands are non-arable and have land-use capability classes varying from IV to VIII. However, the arable lands generally belong to class II and class III (Sur et al., 1998). These soils are deep, medium to light textured with low to good water retentive capacity having gentle to moderate slope.

Chemical and physical characteristics

The soil chemical and physical characteristics of the soil samples under land-use fallow, arable, forest, and grasslands are presented in Tables 1 and 2. The soils were sandy loam and loamy sand in texture with sand content varying from 78.2 to 83.2 and 75.8 to 83.2%, silt from 5.4 to 9 and 7.1 to 9.5%, and clay content from 11.4 to 12.8 and 9.7 to 14.7% in the area, respectively.

The pH of the soils varied from 7.8 to 8.3, and electrical conductivity from 0.94 to 1.6 dS m-1. The organic matter content varied in soils under land-uses that are fallow (0.15%), arable (0.37%), forest (0.45%), and grasses (0.70%) with the texture sandy loam. However, it differed under land-uses fallow (0.13%), arable (0.40%), forests (0.58%) and grasses (0.67%) respectively with texture loamy sand (Table 2).

Aggregate sampling procedure

Natural, undisturbed aggregates were collected from three different sites under each land-use viz. fallow, arable, forest, and grasses with two soil textures. After analyzing for soil texture, big clods of about 30-35 mm in diameter were collected with the help of a spade up to a depth of 15 cm from 4 places within a site. However, under land-use grasses, the land is cleared of native vegetation before the collection of aggregate samples. Under the land-use forest, the samples were collected after clearing the land surface of the accumulated litter. The sampling sites selected for land-use arable were without any crop cover. The bigger clods under the four land-uses were brought carefully to the laboratory so as avoid their breakage. The clods were then allowed to fall freely from a height of 90-100 cm to obtain the aggregates formed by breaking at natural cleavage points. These aggregates were then categorized into

Table 1. Chemical and physical characteristics of soils under different land-uses at site- I

Properties	Land-use			
	Fallow	Arable	Forests	Grasses
pH	8.1	7.9	7.8	8.0
Electrical conductivity (dS m^{-1})	0.94	1.6	1.3	1.1
Organic matter content (%)	0.15	0.37	0.45	0.70
Sand, %	78.2	80.4	82.2	83.2
Silt, %	9.0	7.6	7.7	5.4
Clay, %	12.8	12.0	10.1	11.4
Texture	Sandy loam	Sandyloam	Sandy loam	Sandy loam

Table 2. Chemical and physical characteristics of soils under different land-uses at site–II

Properties	Land-use			
	Fallow	Arable	Forests	Grasses
pH	8.0	7.8	8.1	8.3
Electrical conductivity (dS m^{-1})	0.95	1.9	1.1	1.4
Organic matter content (percent)	0.13	0.32	0.41	0.64
Sand, %	87.8	89.6	85.5	83.2
Silt, %	4.5	6.3	8.4	7.1
Clay, %	7.7	4.1	6.1	9.7
Texture	Loamy sand	Loamy sand	Loamy sand	Loamy sand

four classes based on their size viz., <3mm, 3-5 mm, 5-10 mm, and 10-20 mm. After that aggregates were oven dried for 24 hours at 40° C temperature to limit moisture variations.

Raindrop simulator

The designed and calibrated single raindrop simulator was employed for determining the disruptability of natural soil aggregates as detailed by Kaur (2002). However, the nozzles of drop sizes 2.5, 3.5, and 4.5 mm were selected to achieve the raindrop size range 2-3, 3-4, and 4-5 mm, respectively. For each nozzle, the total volume of water was collected for 200 drops. It was measured with a measuring cylinder. Diameters of falling raindrops were then cross-checked, using the flour pellet method (Hudson, 1993)

Experimental details

Aggregates of four different sizes viz. <3mm, 3-5 mm, 5-10 mm, and 10-20 mm were collected from 4 different land-uses (fallow, arable, forest, and grasses). These were subjected to raindrops (single) of sizes 2.5, 3.5, and 4.5 mm (through rainfall simulator) at three initial moisture levels viz. air dry, field capacity, and saturation. These were replicated thrice. The air-dry aggregates were weighed and subjected to the impact of falling raindrops (from a fall height of 2m) and kept on a sand bath till their complete disruption was noticed. After that, the number of raindrops used to do so was recorded. For the initial moisture content at field capacity, the aggregates were saturated overnight and then drained at 0.2 bar suction. However, the aggregates at field capacity and saturation moisture contents were weighed separately after air drying them. In addition, every effort was made to select aggregates of similar size and weight from each size group. The distilled water at room temperature was used for the simulation of raindrops to avoid the effect of various salts as well as temperature.

The relationship between flour pellet mass (obtained from the flour pellet method of drop size distribution) and drop mass; flour pellet mass and the drop size were also derived after allowing raindrops to fall from the height of 2 m. This was achieved to study the effect of falling raindrops at a specified height on the pellet mass and size. About 94-99% of the variation in drop mass could be explained due to the pellet mass. Similarly, the variation of 96-97% in drop size could also be explained due to the pellet mass.

Erodibility index

The erodibility index of aggregates was computed in terms of the kinetic energy of all the raindrops used for their complete disruption. The kinetic energy was then used to characterize the soils for their erodibility index. The same can be expressed in the form listed below.

$$EI_{SRT} = 1/\,N\,(1/2\ m\ v^2) \qquad \ldots(1)$$

Where, EI_{SRT} is the erodibility index based on the single raindrop technique, N is the number of raindrops used to completely disrupt an aggregate per gram of soil, 'm' is the mass of a single raindrop of respective size, and 'v' is the computed terminal velocity of the respective raindrop(s). However, in this computation, the height of the fall of raindrops was kept at 2m. Thereby, it achieved about 95% of the terminal velocity of the falling raindrops.

Particle size distribution

The determination of particle size distribution was made using the International Pipette method (Day, 1965). The size fractions of the samples, as per the USDA system of classification were determined by dispersing the samples with 2% sodium hexametaphosphate, pretreated with H_2O_2 to remove organic carbon. Sand size particles were then determined using a wet sieving procedure with a 300-mesh sieve followed by drying and weighing. Silt and clay contents were determined in the suspension through the withdrawal of soil water suspension taken from a fixed depth of 10 cm from the top of the sedimentation cylinder after allowing settling timings, as per the Stokes law. In these soils, water suspension samples were transferred to pre-weighed and dried beakers of 50 ml capacity. The samples were later dried in an oven at 105°C temperature till constant weight was achieved. Then the amounts of sand, silt, and clay fractions were computed.

Aggregate size distribution

The aggregate size distribution was determined using the wet sieving technique of Van-Bavel (1949). The results were expressed as% water-stable aggregates >0.5 mm in size. To represent the aggregation status of soils by a single value, both the mean weight diameter (MWD) and the geometric mean weight diameter (GMD) were calculated as follows:

$$\text{MWD} = \frac{\sum_{i=1}^{n}(d_i w_i)}{\sum_{i=1}^{n} W_i} \quad \ldots(2)$$

$$\text{GMD} = \exp \frac{\sum_{i=1}^{n}(w_i \log d_i)}{\sum_{i=1}^{n} W_i} \quad \ldots(3)$$

Where d_i, is the mean diameter of each size fraction in mm, n is the number of size fractions and w_i is the weight of aggregates occurring in the corresponding size fraction.

Root mass density

The aggregates of each size class were weighed. After that, the pre-weighed clods were wrapped in nylon mesh. After that, aggregates were individually washed under tap water to separate the roots from the soils. The roots were then oven dried at 60°C for 24 hours and weighed. Then root mass density (RMD) per unit soil aggregate volume was computed as follows:

$$RMD = \frac{Root\,weight\,(mg)}{Aggregate\ volume\,(cm^3)} \quad \ldots(4)$$

pH

The soil pH was determined in 1:2 soil-water suspensions using an Elico-glass electrode pH meter (Jackson, 1967).

Electrical conductivity

The electrical conductivity of the samples was determined in 1-2 soil-water suspension equilibrated after 24 hours using a conductivity bridge.

Organic carbon

The organic carbon was determined using Walkley and Black's rapid titration method as detailed by Piper (1950).

Statistical analysis

The data for all the experimental variables were statistically analyzed following a Completely Randomized Design (CRD) with 4 land-uses, 4 aggregate sizes and 3 moisture contents, and 2 texturally different soils for determining the significance of differences among the various treatment means (Gomez and Gomez, 1984).

However, an overall test of the coincidence of two nonlinear regressions was made to assess if the two data sets were significantly different. The two data sets correspond to the MWDs obtained for various cumulative rainfalls applied to two distinct initial aggregate size classes. The objective was to test the hypothesis so that the two regression curves were similar. The principle of this test was to obtain variability with only one model to the residual variability obtained with the two distinct models fitted for each set of experimental data. For this, the two data sets were fitted with two distinct power functions of the rainfall variable, and the residual variability S^2_{yxa}, for 2 soil types was calculated.

The same was done by fitting a unique model to both data sets and S^2yxb was calculated and the difference was computed by:

$$S^2_{yxc} = ((n_1+n_2-2)\ S^2_{yxb} - (n_1+n_2-4)\ S^2_{yxa}))/2 \quad \ldots(5)$$

xa = rainfall for event A

xb = rainfall for event B

S^2_{yxb} = residual variability in rainfall amount of event xb

S^2_{yxa} = residual variability in rainfall amount of event xa

S^2_{yxc} = variability showing the newly computed rainfall amount

where, n_1 and n_2 are the number of calculated values for each of the two aggregate size classes. However, later, the quantification was made through relative improvement by the distinct models against one by calculating the value of the Fisher-Snedecor test (F) as

$F = S^2_{yxc} / S^2_{yxa}$

If, $F > n_1+n_2-4$, the null hypothesis (H_0) was rejected, meaning that a significantly better fit was obtained by considering two distinct models.

RESULTS AND DISCUSSION

Disruption of aggregates of loamy sand soils as affected by land-uses and moisture contents with raindrop size 2.5 mm

The disruption of different-sized aggregates at different moisture contents on loamy sand soils is presented in Table 3. The erodibility index at air-dry aggregate moisture content varied from 1.48 to 5.34, 0.91 to 3.37, 0.74 to 2.81, and 0.44 to 1.63 respectively under land-use fallow, arable, forest, and grasses. The maximum erodibility index of aggregates was observed under land-use fallow which was significantly more than that with land-uses arable, forest, and grasses at air-dry moisture content. This demonstrated that the aggregates under land-use grasses were more stable.

However, at field capacity, the erodibility index of aggregates varied from 1.53 to 5.76, 1.23 to 3.89, 1.19 to 3.19, and 0.84 to 2.06 respectively under land-use fallow, arable, forest, and grasses. However, at field capacity moisture content, the maximum erodibility index of aggregates was noticed under land-use fallow (3.27) and minimum under land-use grasses (1.45).

Similarly, at saturation, the erodibility index varied from 1.73 to 5.99, 1.41 to 4.25, 1.37 to 3.87, and 1.01 to 3.54 respectively under land-use fallow, arable, forest and grasses. However, the results suggested that the aggregates were most erodible under land-use fallow and least erodible under land-use grasses, irrespective of their moisture content.

Thereby, at different levels of moisture content, the maximum disruption of aggregates was noticed under land-use fallow due to lack of vegetative cover and low organic matter (0.08 mg/cm^3) content (Table 4). It was also known that the number of finer fractions of soil organic C was associated with soil particles. These were lost with the runoff and erosion processes. The minimum disruption of aggregates was noticed under land-use grasses due to more vegetative cover and the aggregate stability might have improved due to higher root mass density (6.11 mg/cm^3) under these land-uses (Table 4). The root mass density under land-use forest varied from 2.15-2.25 mg/cm^3 and 1.25-1.40 mg/cm^3 on land-use arable with two types of soils. This demonstrated that the lesser erodibility index was noticed under land-use forest than that under fallow and arable. The root mass density observed was more under each land-use arable and forest compared to the fallow on both types of soils.

The disruption of aggregate increased with an increase in size under land-use. The maximum disruption was observed in 10-20 mm aggregate size (3.29-4.41) followed by 5-10 mm (2.22-2.65), 3-5 mm (1.46-1.84) and <3 mm (0.89-1.38) respectively

Table 3. Effect of land-use on disruption of different-sized aggregates at different moisture contents using raindrop size 2.5 mm on loamy sand soils

AggregateSize (mm)	Land-use				Mean
	Fallow	Arable	Forests	Grasses	
			Air Dry		
<3 mm	1.48	0.91	0.74	0.44	0.89
3-5 mm	2.11	1.44	1.29	0.98	1.46
5-10 mm	3.57	2.24	1.82	1.24	2.22
10-20 mm	5.34	3.37	2.81	1.63	3.29
Mean	3.13	1.99	1.67	1.07	
			Field Capacity		
<3 mm	1.53	1.23	1.19	0.84	1.20
3-5 mm	2.16	1.61	1.34	1.27	1.60
5-10 mm	3.61	2.43	2.03	1.64	2.43
10-20 mm	5.76	3.89	3.19	2.06	3.73
Mean	3.27	2.29	1.94	1.45	
			Saturation		
<3 mm	1.73	1.41	1.37	1.01	1.38
3-5 mm	2.41	1.84	1.71	1.41	1.84
5-10 mm	3.92	2.91	2.62	1.16	2.65
10-20 mm	5.99	4.25	3.87	3.54	4.41
Mean	3.51	2.60	2.39	1.78	
L.S.D. (p=0.05)	Air Dry	Field Capacity	Saturation		
LU	0.31	0.43	0.18		
AS	0.27	0.39	0.16		
LU × AS	0.49	0.74	0.29		

LS = Land-use, AS = Aggregate size

Table 4. Average root mass density (mg/cm^3) under different land-uses on Sandy loam and Loamy sand soils

Land-use	Root mass density (mg/cm^3) of Sandy loam soils	Root mass density (mg/cm^3) of Loamy sand soils
Fallow	0.08	0.06
Arable	1.40	1.25
Forests	2.25	2.15
Grasses	6.11	6.00

(Table 3). The study by Mc Calla (1944) also observed that a greater number of raindrops were required to disrupt the smaller-sized aggregates than that the bigger-sized aggregates. The smaller-sized aggregates were more stable against disruption mainly due to the formation of organo-mineral complexes. However, the smaller aggregates were not large enough to absorb the complete impact of the falling raindrops. Therefore, more raindrops were required per unit weight to break the smaller aggregates than the bigger aggregates; those have more cleavage points, thereby making them more erodible (Singh, 2008).

The disruption of aggregates of size less than 3 mm at air-dry moisture content was not significantly different under land-use fallow than that under land-use grasses, forest, and arable soils. At field capacity moisture content, no significant difference was observed in the disruption of aggregates among the different land-uses. At saturated moisture content, maximum disruption of aggregates was observed under land-use fallow and minimum under grasses, whereas disruption of aggregates under land-use forest and arable did not differ significantly.

The disruption of aggregates of 3-5 mm size, at air dry aggregate moisture content, and field capacity moisture contents did not differ significantly under all land-uses except under land-use fallow. However, at saturated moisture content, the disruption of aggregates under land-use forest and arable did not differ significantly.

However, on the aggregate size of 5-10 mm, the disruption of aggregates under land-use forest and arable did not differ significantly at air-dry and saturated moisture contents. Similarly, at field capacity moisture content, the disruption of aggregates under land-use grasses and the forest did not differ significantly. Similarly, with the same moisture content, the disruption of aggregates under land-uses forest and arable did not differ significantly. However, the disruption of aggregates under land-use fallow was significantly higher over the other land-uses. However, in 5-10 mm aggregate size, more disruption of aggregates was noticed over 10-20 mm aggregate size than that in other sized aggregates under all land-uses.

Effect of land-use on disruption of aggregates of sandy loam soils at different moisture contents with raindrop size 2.5 mm

The disruption varied from 0.89 to 2.94 at air-dry moisture content irrespective of land-use (Table 5). The maximum disruption was observed under land-use fallow (2.94) followed by arable (1.78), forests (1.43), and grasses (0.89), at air-dry moisture content. The minimum disruption was observed on land-uses forest and grasses (0.89) which is significantly lower than that on other land-uses. At field capacity moisture content, the maximum disruption was observed on land-use fallow (3.10) and the minimum on grasses (1.31). Similarly, at saturated moisture content, disruption was highest on land-use fallow (3.40) and least on grasses (1.69). At different moisture contents, the land-use fallow had maximum disruption due to the low organic matter content and lesser root mass density. However, the minimum disruption was observed on land-use grasses soils due to the higher amount of organic matter content and root mass density (Table 4).

The disruption under air dry aggregates varied from 0.69 to 3.08 on aggregate sizes less than 3 mm to 10-20 mm (Table 5). The maximum disruption of 3.08 was observed on 10-20 mm sized aggregates and a minimum of 0.69 in aggregates of size <3 mm. At field capacity moisture content, a maximum disruption of 3.55 was observed on an aggregate of size 10-20 mm and a minimum of 1.02 on the aggregate of size <3mm.

The results demonstrate that the bigger-sized aggregates required a smaller number of raindrops than the smaller-sized aggregates because bigger aggregates can completely absorb the impact of falling raindrops. Thereby, a bigger aggregate disrupts easily. At air-dry aggregates, the disruption ability between grassland and forest soils, and forest and arable soils did not differ significantly. At field capacity moisture content through the aggregate of size 3-5 mm, the disrupt ability did not differ significantly under forest and grassland soils. At the same moisture content, the land-use fallow was more disrupted compared to other land-uses under the

Table 5. Effect of land-use on disruption of different-sized aggregates at different moisture contents using raindrop size 2.5 mm on sandy loam soils

AggregateSize (mm)	Land-use				Mean
	Fallow	Arable	Forests	Grasses	
		Air Dry			
<3 mm	1.29	0.70	0.50	0.26	0.69
3-5 mm	1.92	1.23	1.05	0.80	1.25
5-10 mm	3.38	2.03	1.58	1.06	2.01
10-20 mm	5.15	3.16	2.57	1.45	3.08
Mean	2.94	1.78	1.43	0.89	
		Field Capacity			
<3 mm	1.36	1.04	0.98	0.70	1.02
3-5 mm	1.99	1.42	1.13	1.13	1.42
5-10 mm	3.44	2.24	1.82	1.50	2.25
10-20 mm	5.59	3.70	2.98	1.92	3.55
Mean	3.10	2.10	1.73	1.31	
		Saturation			
<3 mm	1.62	1.22	1.24	0.92	1.25
3-5 mm	2.30	1.65	1.58	1.32	1.71
5-10 mm	3.81	2.72	2.49	1.07	2.52
10-20 mm	5.88	4.06	3.74	3.45	4.28
Mean	3.40	2.41	2.26	1.69	
L.S.D. (p=0.05)	Air Dry	Field Capacity	Saturation		
LU	0.28	0.37	0.13		
AS	0.23	0.31	0.11		
LU × AS	0.43	0.63	0.21		

LU = Land-use, AS = Aggregate size

same aggregate size. In 5-10 mm aggregate size, the disruption of the aggregates under all the land-uses was significantly different except at field capacity moisture content where disruptability between land-uses the forest and arable did not differ significantly. In 10-20 mm aggregate size, all the land-uses had significantly different disruption abilities. However, it was highest on land-use fallow and least under grasses.

Aggregates having a t value >1.96 shows a significant difference in their disruptability at 5%. The loamy sand aggregates had more disruption than Sandy loam aggregates under all the land-uses at air-dry and saturated moisture content (Table 6). The t-statistics showed significantly higher t-values in magnitude in sandy loam soils over loamy sand soils. This further suggested at each moisture content, the disrutability of aggregates was higher in magnitude for sandy loam soils over loamy sand soils with raindrop size 2.5 mm.

At field capacity, the disruption of aggregates differed significantly under land-use fallow of loamy sand soils than that on sandy loam soils. In general, the effects of land-use were similar in the disruption of aggregates on two texturally different soils.

Effect of land-use on disruption of aggregates of loamy sand soils at different moisture contents with raindrop size 3.5 mm

A similar trend was observed in the disruption of loamy sand soils against raindrops of size 3.5 mm through raindrops of size 2.5 mm irrespective of land-use and aggregate size (Table 7). At air-dry

Table 6. The t-Statistics as affected by land-use and moisture contents on disruption of aggregates using raindrop size 2.5 mm on two texturally different soils

	Land-use			
	Fallow	Arable	Forests	Grasses
		Air Dry		
Sl	3.13	1.99	1.67	1.07
Ls	2.94	1.78	1.43	0.89
t-value	2.08**	1.98**	2.14**	2.21**
		Field Capacity		
Sl	3.27	2.29	1.94	1.45
Ls	3.10	2.10	1.73	1.31
t-value	1.99**	1.78	1.61	1.69
		Saturation		
Sl	3.51	2.60	2.39	1.78
Ls	3.40	2.41	2.26	1.69
t-value	1.99**	1.97**	2.01**	2.07**

** Significant at 5% level

Table 7. Effect of land-use on disruption of different-sized aggregates at different moisture contents using raindrop size 3.5 mm on loamy sand soils

AggregateSize (mm)	Land-use				Mean
	Fallow	Arable	Forests	Grasses	
		Air Dry			
<3 mm	0.71	0.56	0.50	0.27	0.51
3-5 mm	1.01	0.89	0.85	0.60	0.84
5-10 mm	1.71	1.39	1.22	0.76	1.27
10-20 mm	2.56	2.09	1.90	0.99	1.89
Mean	1.50	1.23	1.12	0.65	
		Field Capacity			
<3 mm	0.73	0.76	0.81	0.51	0.70
3-5 mm	1.04	1.00	0.91	0.77	0.93
5-10 mm	1.73	1.51	1.38	1.00	1.41
10-20 mm	2.76	2.41	2.17	1.26	2.15
Mean	1.57	1.42	1.32	0.89	
		Saturation			
<3 mm	0.83	0.80	0.71	0.62	0.74
3-5 mm	1.16	1.12	1.00	0.86	1.04
5-10 mm	1.88	1.78	1.38	0.71	1.44
10-20 mm	2.88	2.62	2.42	2.16	2.52
Mean	1.69	1.61	1.38	1.09	
L.S.D. (p=0.05)	Air Dry	Field Capacity	Saturation		
LU	0.10	0.09	0.10		
AS	0.12	0.15	0.14		
LU × AS	0.21	0.21	0.24		

LS = Land-use, AS = Aggregate size

moisture content, the maximum disruption was observed under land-use fallow (1.50) and minimum on grasses (0.65). At field capacity moisture content, the maximum disruption was observed under land-use fallow s (1.57) followed by arable (1.42), forest (1.32), and grasses (0.89). At field capacity moisture content, the disruption of aggregate under land-uses arable and the forest was the same. Whereas, at saturated moisture content, the disruption under all land-uses differs significantly. The maximum disruption was observed on land-use fallow (1.69) and minimum on land-use grasses (1.09). This may be attributed to the more binding of the soil particles together on land-use grasses, thereby, making these more resistant to the disruptive forces of raindrops. However, the land-uses grasses with maximum root mass density were least disrupted (Table 4). Whereas, under land-use fallow, aggregates were more disrupted due to less root mass density (Table 4). Also, the organic matter content significantly affected the disruption of aggregates under land-use.

The disruption of aggregate at all the moisture contents increases with the increase in the size of the aggregate. It was however lower under 3.5 mm raindrop size than that under 2.5 mm sized aggregates. The disruptability of aggregate less than 3 mm in size was minimum at air-dry moisture content and maximum at saturated moisture content irrespective of land-use (Table 7). The disruptability at field capacity moisture content lies between air-dry and saturated moisture conditions, irrespective of land-use. A similar trend was observed on other aggregate sizes where maximum disruption of aggregates was observed on 10-20 mm aggregates at all moisture contents. The interactive effects of the land-use and aggregate size on the soil disruption ability were significant at all moisture contents. The disruption of aggregates of size less than 3mm under fallow, arable, and forest land-uses was not significantly different from each other in all the moisture contents. At saturated moisture content, the aggregate disruption was similar under all the land-uses. However, the 10-20 mm sized aggregates were similar in their disruption under land-uses arable and forest at all the moisture contents.

Effect of land-use on disruption of aggregates of sandy loam soil at different moisture contents with raindrop size 3.5

At air-dry moisture content on sandy loam soil, maximum disruption was observed on fallow soils (1.41) followed by arable (1.10), forest (0.97), and grassland (0.54) soils (Table 8). The disruption processes under all the land-use differ significantly. At field capacity and saturated moisture content, a similar trend was observed in the disruption of each aggregate size as at air-dry aggregates. The maximum disrupt ability of aggregates was observed under land-use fallow and the minimum under grasses. However, except at field capacity moisture content where the disruptability of aggregates under land-uses arable and the forest did not differ significantly.

The disruptability of aggregate increased at all the moisture contents with an increase in aggregate size. The minimum disruption was observed at air-dry moisture content with an aggregate of size less than 3 mm and the maximum at saturated moisture content. However, the disruption of aggregates was maximum at all the moisture contents in 10-20 mm aggregate size. The interactive effects of the land-use and aggregate size on aggregate disruption were significant in all moisture contents (Table 9).

The disruption of an aggregate of size less than 3 mm at air-dry moisture content was the same under land-uses grasses and forest, forest and arable, and arable and fallow. Whereas at field capacity moisture content, the disruption under all the land-uses did not differ significantly. At saturated moisture content, the land-uses grasses, forest, and arable did not differ significantly in the disruption of aggregates. However, aggregates of size less than 10-20 mm size at air-dry moisture content disrupt ability of aggregates under land-uses arable and the forest did not differ significantly. At field capacity moisture content all the land-uses differed significantly in the disruption of aggregates. Whereas at saturated moisture content, the land-uses such as forest and grasses did not differ significantly in disrupting the aggregates.

Therefore, it can be concluded that the disruptability of aggregates at air-dry moisture content was maximum with loamy sand soils than that than that on sandy loam soils under all the land-uses (Table 9). Further, t-values indicated that at each moisture content , the disrutability of aggregate was higher in magnitude in sandy loam soils than that loamy sand soils with rain drop size 3.5 mm.

But at field capacity moisture content, the land-use fallow than that other land-uses demonstrated

Table 8. Effect of land-use on disruption of different-sized aggregates at different moisture contents using raindrop size 3.5 mm on sandy loam soils

Aggregate Size (mm)	Land-use				Mean
	Fallow	Arable	Forests	Grasses	
			Air Dry		
<3 mm	0.62	0.43	0.34	0.16	0.39
3-5 mm	0.92	0.76	0.71	0.49	0.72
5-10 mm	1.62	1.26	1.07	0.65	1.15
10-20 mm	2.47	1.96	1.75	0.88	1.77
Mean	1.41	1.10	0.97	0.54	
			Field Capacity		
<3 mm	0.65	0.64	0.67	0.43	0.60
3-5 mm	0.96	0.88	0.77	0.69	0.82
5-10 mm	1.65	1.39	1.24	0.92	1.30
10-20 mm	2.68	2.29	2.03	1.17	2.04
Mean	1.49	1.30	1.17	0.80	
			Saturation		
<3 mm	0.78	0.76	0.70	0.56	0.70
3-5 mm	1.10	1.02	0.78	0.81	0.93
5-10 mm	1.83	1.69	1.26	0.65	1.36
10-20 mm	2.82	2.52	2.12	2.10	2.39
Mean	1.63	1.50	1.22	1.03	
L.S.D. (p=0.05)	Air Dry	Field Capacity	Saturation		
LU	0.12	0.13	0.10		
AS	0.12	0.13	0.10		
LU × AS	0.24	0.25	0.20		

LU = Land-use, AS = Aggregate size

Table 9. The t-statistics as affected by land-use and moisture contents on disruption of aggregates using raindrop size 3.5 mm on two texturally different soils

	Land-use			
	Fallow	Arable	Forests	Grasses
		Air Dry		
Ls	1.50	1.23	1.12	0.65
Sl	1.41	1.10	0.97	0.54
t-value	2.01**	2.07**	1.99**	1.96**
		Field Capacity		
Ls	1.57	1.42	1.32	0.89
Sl	1.49	1.30	1.17	0.80
t-value	2.11**	1.69	1.54	1.72
		Saturation		
Ls	1.69	1.58	1.38	1.09
Sl	1.63	1.50	1.22	1.03
t-value	1.97**	2.04**	1.99**	2.02**

**Significant at 5% level

more disrupt ability with loamy sand soils. At saturated moisture content, all the land-uses differed significantly in disrupting the aggregates. The results suggested that maximum disruption of aggregates was noticed under land-use fallow and minimum on grasses with loamy sand soils.

Effect of land-use on disruption of aggregates of loamy sand soil at different moisture contents with raindrop size 4.5 mm

The effect of land-use on the disruption of different-sized aggregates at different moisture contents with loamy sand soils is presented in Table 10. The disruption of aggregates demonstrated the same pattern with the raindrop size of 2.5 and 3.5 mm. The disruptability of different-sized aggregates was significantly different from each other under a land-use. At air-dry moisture content, the maximum disruption of aggregates was noticed under land-use fallow (1.34) and minimum under grasses (0.52). Whereas, at field capacity moisture content, maximum disruption of aggregates was noticed under the land-use fallow followed by arable, forest, and grasses. However, no differences were observed in the disruption of aggregates under the land-uses arable and forest. At saturated moisture content, all the land-uses differed significantly in disrupting the aggregates; however, it was of maximum magnitude under land-use fallow followed by land-use such as arable, forest, and grasses.

The minimum disruption of aggregates was noticed under land-use grasses due to more

Table 10. Effect of land-use on disruption of different-sized aggregates at different moisture contents using raindrop size 4.5 mm on Loamy sand soils

Aggregate Size (mm)	Land-use				Mean
	Bare	Arable	Forests	Grasses	
			Air Dry		
<3 mm	0.63	0.52	0.37	0.21	0.43
3-5 mm	0.90	0.82	0.65	0.48	0.71
5-10 mm	1.53	1.28	0.92	0.61	1.08
10-20 mm	2.28	1.92	1.41	0.80	1.60
Mean	1.34	1.14	0.84	0.52	
			Field Capacity		
<3 mm	0.70	0.65	0.60	0.41	0.59
3-5 mm	0.92	0.75	0.67	0.62	0.74
5-10 mm	1.54	1.10	1.02	0.80	1.12
10-20 mm	2.46	2.10	1.98	1.01	1.89
Mean	1.41	1.15	1.07	0.71	
			Saturation		
<3 mm	0.74	0.70	0.65	0.49	0.65
3-5 mm	1.03	0.93	0.86	0.69	0.88
5-10 mm	1.67	1.50	1.32	0.57	1.27
10-20 mm	2.56	2.32	1.95	1.73	2.14
Mean	1.50	1.36	1.20	0.87	
L.S.D. (p=0.05)	Air Dry	Field Capacity	Saturation		
LU	0.18	0.15	0.12		
AS	0.20	0.12	0.13		
LU × AS	0.38	0.28	0.25		

LU = Land-use, AS = Aggregate size

accumulation of organic matter and phyto mass annually. Growing plants retarded the decomposition of organic matter in soils (Jenkinson and Johnston, 1977). However, continuously cultivating the fields declined the organic matter resulting in a decrease in water-stable aggregates. This suggested the aggregates under land-use fallow demonstrated maximum disruption of aggregates due to lesser organic matter in them. A significant increase in aggregate disruption was observed with an increase in aggregate size at all moisture contents irrespective of land-uses. The disruption of aggregates of size <3 mm varied from 0.43 to 0.65 while that of sizes viz., 3-5, 5-10, and 10-20 mm varied from 0.71 to 0.88, 1.08 to 1.27, and 1.60 to 2.14, respectively. However, the bigger-sized aggregates were noticed to be more erodible and these could be associated with a greater number of cleavage points (Kaur, 2002). Whereas the smaller sized aggregates were not able to bear the impact of falling raindrops completely, thus, suggesting that greater numbers of such raindrops are required to break these aggregates. A similar kind of analogy has been proposed by Mc Calla (1944).

However, to explain the greater resistance offered by the largest aggregates, it is hypothesized that the clay content and or the organic matter content increases as the aggregate size increases. The stable micro aggregates of cultivated soils (Puget *et al.*, 1995) were often enriched in total C than with soil micro aggregates in non-cultivated soils (Cambardella and Elliott, 1993; Puget *et al.*, 2000). In the resulting aggregate size distribution under land-use, the relative importance of each mode varied with the clay content (Le Bissonnais, 1988). The association of higher clay content might be responsible for differences in the sizes of the MWDs in texturally different soils. Le Bissonnais (1988) proposed the breakdown of aggregates occurs progressively from the periphery to the center of aggregates by keeping the duration of the energy applied the same for all initial aggregate sizes. Therefore, it is logical to obtain a greater MWD for the coarser initial aggregate size classes even if the MWD were expressed with a size >2000 μm fraction.

Effect of land-use on disruption of aggregates of sandy loam soils at different moisture contents with raindrop size 4.5 mm

The effect of land-use on the disruption of different-sized aggregates at different moisture contents on sandy loam soils is elaborated in Table 11. The disruption of aggregate size was similar to raindrops of size 2.5 and 3.5 mm. However, the disruption of aggregates differed significantly from each other with the land-use. At air-dry moisture content, the maximum disruption of aggregate was noticed under land-use fallow (1.25) and minimum in grasses (0.44). At field capacity moisture content, the disruption of aggregates followed the same trend. The land-uses of arable and forests did not differ significantly in their disruptability. At saturated moisture content, the aggregates of all sizes differed significantly from each other in their disruption under different land-uses. The study by Kahlon and Khera (1997) observed that soil loss was significantly lower under land-use forest and grasses than that under arable and fallow. The study further demonstrated the maximum mean weight diameter under land-uses forest and grasses, and minimum under fallow with water stable aggregates of size>0.25 mm. A significant increase in disrupted aggregates was noticed with the increase in aggregate size at all the moisture contents.

The disruption of an aggregate of size <3 mm varied from 0.33 to 0.57 mm; while that of size 3-5, 5-10, and 10-20 mm varied from 0.61 to 0.83, 0.98 to 1.23, and 1.50 to 2.07 mm, respectively. A decrease in disruption of aggregates with an increase in the size of aggregates might be attributed due to more volume of air entrapped in the aggregates, especially at air-dryness and field capacity moisture content. However, it tries to rush out during the wetting process of aggregate, resulting in the early and easy breakdown of aggregates. Further, significantly higher t-statistics were observed under each land-use and moisture content on loamy sand soils over the sandy loam soils. The interactive effect of an aggregate of size <3 mm and land-use were similar in all moisture contents (Table 11). However, with an aggregate of size 3-5 mm, the land-use fallow differed significantly from the land-use grasses in disrupting the aggregate. The aggregate of sizes 10-20 mm at air-dry moisture content differed significantly in their disruptability under land-use. But at field capacity moisture content, the aggregates under land-use arable and the forests did not differ significantly in their disrupt ability. Similarly, at saturated moisture content, the land-uses forests and grasses, and fallow and arable did not differ significantly.

Table 11. Effect of land-use on disruption of different sized aggregates at different moisture contents using raindrop size 4.5 mm on Sandy loam soils

Aggregate Size (mm)	Land-use				Mean
	Fallow	Arable	Forests	Grasses	
			Air Dry		
<3 mm	0.55	0.40	0.25	0.13	0.33
3-5 mm	0.82	0.70	0.53	0.39	0.61
5-10 mm	1.44	1.16	0.80	0.52	0.98
10-20 mm	2.23	1.80	1.29	0.71	1.51
Mean	1.26	1.02	0.72	0.44	
			Field Capacity		
<3 mm	0.58	0.50	0.49	0.34	0.48
3-5 mm	0.85	0.70	0.64	0.55	0.69
5-10 mm	1.47	0.99	0.92	0.73	1.03
10-20 mm	2.39	2.02	1.85	0.94	1.80
Mean	1.32	1.05	0.98	0.64	
			Saturation		
<3 mm	0.69	0.60	0.52	0.45	0.57
3-5 mm	0.98	0.90	0.80	0.64	0.83
5-10 mm	1.63	1.50	1.25	0.52	1.23
10-20 mm	2.49	2.20	1.90	1.68	2.07
Mean	1.45	1.30	1.12	0.82	
L.S.D. (p=0.05)	Air Dry	Field Capacity	Saturation		
LU	0.20	0.15	0.14		
AS	0.19	0.16	0.15		
LU × AS	0.42	0.29	0.29		

LU = Land-use, AS = Aggregate size

Table 12. The t-statistics as affected by land-use and moisture content on disruptability of aggregates using raindrop size 4.5 mm on two texturally different soils

	Land-use			
	Fallow	Arable	Forests	Grasses
		Air Dry		
Ls	1.34	1.14	0.84	0.52
Sl	1.26	1.02	0.72	0.44
t-value	2.16**	1.99**	2.04**	2.00**
		Field Capacity		
Ls	1.41	1.15	1.07	0.71
Sl	1.32	1.05	0.98	0.64
t-value	2.07**	1.74	1.43	1.79
		Saturation		
Ls	1.50	1.36	1.20	0.87
Sl	1.45	1.30	1.12	0.82
t-value	1.96**	2.12**	2.01**	2.08**

** Significant at 5% level

CONCLUSION

The disruptability of aggregates at air-dry moisture content was maximum with loamy sand soils than that on sandy loam soils under all the land-uses. But at field capacity moisture content, the land-use fallow than that other land-uses demonstrated more disruptability with loamy sand soils. At saturated moisture content, all the land-uses differed significantly in disrupting the aggregates. The results suggested that maximum disruption of aggregates was noticed under land-use fallow and minimum on grasses with loamy sand soils. However, at saturated moisture content, the disruption of aggregates of loamy sand soils followed a similar trend as that at air-dry moisture content. However, the mechanical breakdown of aggregate under raindrop impact is an important process for wet soils because the aggregates become weaker with an increase in wetness (Le Bissonnais, 1996). In addition, the breakdown of an aggregate is proportional to the duration of the kinetic energy possessed by the rainfall event (Le Bissonnais, 1988). However, for 3-5 mm aggregate size, size distributions were similar to the stirring treatment and the rainfall simulation. In addition, the raindrop effect was rapid with smaller-sized aggregate. Once the aggregates were completely wet during the stirring treatment, the aggregates receive both mechanical and kinetic energy. Thereby, the difference in the magnitude of the disruption ability of aggregate under land-use depends on raindrop size, soil type, organic matter content, silt, clay content, and ultimately the moisture content (Singh, 2008).

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