Response of Soil Macro and Micro-Aggregates and Dispersion Ratio to Solid Cattle Manure in Cultivated and Non- cultivated Soils

ABSTRACT

Effect of solid cattle manure (SCM) application on soil macro and micro-aggregates (Large soil macro-aggregates >2 mm, small macro-aggregates 0.25- 2 mm and soil micro-aggregates < 0.053- 0.25 mm) and dispersion ratio in cultivated and non- cultivated soil was studied. Four rates of SCM were added to the soil before tilth: 0, 12, 24 and 36 Mg ha^{-1} using two field experiments. The first designed to study the effect of SCM on soil aggregation (non-cultivated soil), and the second to study the effect of SCM and growing potatoes on soil aggregation (cultivated soil). The SCM increased soil porosity, and saturated hydraulic conductivity while decreased bulk density due to increasing aggregation in the non-cultivated soil compared to the cultivated one. The aggregates large soil macro-aggregates, small macro-aggregates and soil micro-aggregates increased by the application of SCM. The effect SCM decreased significantly the dispersion ratio. SCM increased significantly the structure coefficient in the non- cultivated compared to the cultivated soil. The SCM has a major direct effect on soil macro and micro-aggregates under potatoes production, particularly at high rates of SCM. The organic matter showed highly significant positive correlations with macro and micro-aggregates and highly negative one with dispersion ratio. A positive correlation was found between the number of tubers and dispersion ratio, as well as between potato yield and macro and micro-aggregates which indicated that the organic matter addition increased the potatoes yield and decreased the dispersion ratio. In conclusion, the SCM improves soil macro and micro-aggregates in cultivated and non-cultivated soil.

Key Words: Macro-aggregates; Micro-aggregates; Dispersion ratio; Structure coefficient; Hydraulic conductivity; Bulk density; Solid cattle manure; Potatoes yield

1. INTRODUCTION

Solid cattle manure (SCM) is an excellent soil amendment capable of increasing soil quality (Dao and Cavigelli, 2003; Zhang *et al.,* 2014). Many studies have shown that balanced application of organic fertilizers can increase soil organic carbon and maintain soil productivity (Chen *et al.,*2009; Sun and Huang, 2011), either directly through supplying nutrients or indirectly through modifying soil physical properties that can improve the root environment and stimulate plant growth (Bassouny and Chen, 2016). Organic applications to soils increase organic matter contents of soil, which can bind soil particles together forming aggregates. This can improve soil structure and favors increasing the downward flow of water into soil (Zhang *et al.,* 2006). Organic application increases soil porosity, pore size distribution and saturated hydraulic conductivity and reduces bulk density (Celik *et al.,* 2004; Yang *et al.,* 2013; Bassouny and Chen, 2016). Overall, physical, chemical and, biological properties of the soil could be improved by organic fertilization (Ould *et al.,* 2010).

Soil structure is defined as the size and arrangement of particles and pores in soils (Martin *et al.,* 2012). Good structure for plant growth on loams and clays can be defined in terms of the presence of pores for the storage of water available to plants, pores for the transmission of water and air, and pores in which roots can grow (Bronick and Lal*,* 2005). A desirable range of pore sizes for a tilled layer occurs when most of the clay fraction is flocculated into micro-aggregates, defined as < 25 mm in diameter, and secondly these micro-aggregates and other particles are bound together into macro-aggregates > 25 mm in diameter (Zhou *et al.,* 2013). The majority of the macro-aggregates should have diameters in the range of 1 to 10 mm (Six *et al.,* 2004).

Soil aggregation is a key indicator of good soil quality since it increases water and nutrient retention, and offers suitable habitats for microbial activity (Feeney *et al.,* 2006; Zhou *et al.,* 2013). Aggregations have been studied by Zhang and Peng, (2006) and Huang *et al.,* (2010) who stated that the internal microstructure of aggregates can provide information regarding soil aggregation processes and soil quality. Soil aggregation processes, and factors affecting them, have been well documented (Six *et al.,* 2004; Bronick and Lal, 2005). Water stable aggregates are major factors that influence soil productivity. Formation, size and stability of aggregates are affected by physical, chemical and environmental conditions (Shirani *et al.,* 2002). Pagliai *et al.* (2004) reported that organic manure improved soil structure.

Tuberculous crops have a significant effect on soil aggregation and dispersion ratio, particularly in soils cultivated with potatoes. Potato (*Solatium tuberosun* L.) is one of the major world food crops. Potato is an economical food and it provides a source of low cost energy to the human diet. Organic manures like cattle manure can play an important role in potato productivity. These sources can reduce the deficiency of soil nutrient and improve soil organic matter and overall soil productivity (Mostafa, 2016). Omar, (1983) found that stability of aggregates after potatoes is less than after clover, cotton or maize and that the size of aggregates after potatoes was smaller. Organic fertilizers have a significant effect on soil aggregation and dispersion ratio under potatoes production, this effect is more pronounced at high organic manure rates (Omar, 1990).The main objective of the current study was to assess the effect of solid cattle manure on macro and micro-aggregates, and dispersion ratio in non- cultivated and cultivated soils with potatoes.

2. MATERILS AND METHODS

2.1 Characterization of Study Site

This study was conducted in Sidie Salim, Kafr El-Sheikh Governorate, Egypt (31°27′N, 30°79′E), and 10 meters above sea level. The climate of the study area is arid to semi-arid characterized by a long hot dry summer, mild winter (mean annual precipitation is 140 to 250 mm) and high evaporation rate with moderately to high relative humidity. The average temperature in summer is 26.6°C.

Soil sampled was taken before the experiment started in December 2015 (0-30 cm soil depth). Soil texture is a silty clay loam having 7.2% coarse sand, 13.7% fine sand, 44.0% silt and 25.1% clay. Main chemical properties are organic matter content of 19.5 g/kg, EC of 0.55 dS/m (soil paste extract) and pH value of 7.4. Solid cattle manure was taken from a local animal farm. Main properties of the solid cattle manure are shown in Table 1.

Table 1
Main properties of solid cattle manure applied to the soil

Properties	**Value**
pH (1:10 SCM/water)	7.51
EC(1:10 SCM/water) (dS m^{-1})	2.71
Organic matter (g kg^{-1})	72.50
Total N (g kg^{-1})	3.40
Total P (g kg^{-1})	4.20
Total K (g kg^{-1})	11.10

2.2 Treatments and Experimental Design

Two field experiments were designed to study the effect of SCM on soil aggregation (under cultivated and non- cultivated soil with potatoes). The design was a randomized complete block with four replicates.The area of the plot was 20 m^2 (5 m long and 4 m width). SCM was added to the soil before tilth at four rates i.e. 0, 12, 24 and 36 Mg ha^{-1}. Plots were planted in the summer season of January 4th, 2016, and harvest was on April 5th, 2016. Potato tubers (*Solatium tuberosun* L.) cv. Lady Rosetta were planted in prepared plots having 25 cm apart between each two successive hills. Each plot soil was sampled between tubers at four different sites, in the cultivated soil and randomly in the non-cultivated soil.

2.3 Soil Sampling and Measurements

The investigated soil was sampled at 0-30 cm depth. Water-stable aggregates were assessed by a wet-sieving method (Cambardella and Elliott, 1994). Field-moist soil was gently crumbled, air-dried, and passed through an 8-mm sieve. Material retained on the sieve was discarded, and visible pieces of crop residues and roots were removed. A 100 g^{-1} soil (dry weight). Sub-sample of soil was distributed on a 2-mm sieve of 20-cm diameter and immersed in about 3 cm of water for 5 min. After immersion, samples were wet sieved by dipping the sieves into water 50 times during a 2-min period, done first with the 2-mm sieve, and then sequentially with 0.250-mm and 0.053-mm sieves. Materials retained in each sieve were washed separately into a 150-ml beaker and allowed to settle for about 20 min. Supernatant water was carefully poured off the beaker and discarded, while water- stable aggregates were transferred into a pre-weighed aluminum tin, oven dried at 100°C, and weighed. Classes of water-stable aggregates were large macro-aggregates (Ag >2 mmϕ), small macro-aggregates (Ag 0.25-2mmϕ), and micro-aggregates (Ag 0.053-0.25mmϕ) expressed as g 100 g^{-1} of dry soil (Wormann and Shapiro, 2007).

The dispersion ratio (DR) was determined by the pipette method; using the two mechanical analyses; one without dispersion and the second using sodium hexametaphosphate as a dispersing agent by Gee and Bauder, (1986). The DR was then calculated according to the following equation:

$$DR = \frac{ScW}{ScA} \times 100 \quad \ldots\ldots\ldots\ldots \quad (1)$$

Where ScW is the percentage of "silt +clay" without dispersion while ScA is the percentage of "silt+ clay" after dispersion**.**

Soil structure was evaluated by the structural coefficient of Shein et al. (2001); the structure coefficient (*SC*) is calculated as:

$$SC = A \div B \quad \ldots\ldots\ldots\ldots \quad (2)$$

Where ***A*** is the percentage of aggregation of particles > 0.25 mm and ***B*** is the percentage of aggregation of particles < 0. 25 mm.

Soil bulk density (BD) was determined on undisturbed soil samples using a steel cylinder of 100 cm^3 using three replicates for each plot. Soil total porosity (TP) was calculated from bulk density and average particle size density (2.65 Mg m^{-3}). Each plot soil was also sampled by the cylinders three times (replicates) to measure the saturated hydraulic conductivity (Ks) in the laboratory using the constant-head method (Klute and Dirksen, 1986). Soil texture was determined by the pipette method. Organic matter was determined by using the modified Walkely and Black method. The pH, EC and total N, P and K were estimated by Rowell, (1995).

2.4 Statistical Analysis and Data Processing

Data were all analyzed using analysis of variance at a 0.05 level, using SPSS11.0 for Windows (*SPSS Inc., Chicago, USA*). A correlation coefficient among the different aggregates properties and DR was based on linear correlation coefficients ($p < 0.05$ and $p < 0.01$).

3. RESULTS AND DISCUSSION

Solid cattle manure (SCM) had a significant effect on soil physical properties. FM application decreased significantly the value of soil bulk density (BD) in the non-cultivated soil. This effect seemed to be pronounced by increasing rate of SCM application where increasing rate of application from 24 to 36 Mg ha^{-1} decreased the BD to by19 to 24%, respectively, compared with zero Mg ha^{-1}. Applying 24 to 36 Mg ha^{-1} manure to the decreased the BD in cultivated soil by 2.87 to 5.59 %, respectively, compared with zero treatment. On the other hand, application of the SCM although decreased also value of BD but this decrease was slight and in significant (Table 2). These results are similar to those reported by Celik *et al.* (2004) and Yang *et al.* (2013). BD values in the non-cultivated soil were significantly less than those of the cultivated soil. This reflects a great effect of tubers density on the BD in the cultivated compared to the non-cultivated soil.

Soil porosity increased significantly due to application of SCM to soil whether cultivated or not. (Table 2). Porosity values were significantly greater in the non-cultivated than in the cultivated soil (54.05 and 47.35%, respectively). SCM increased directly soil organic matter leading to improve in soil aggregation and consequently increases in aggregation of particles of >2 mm, 0.25 -2 mm and < 0.053- 0.25 mm, and conversely decreases in values of bulk density with a final product of increasing total porosity (Shirani *et al.* 2002).

Saturated hydraulic conductivity (*Ks*) significantly increased due to SCM application to both soils. Such a result is in agreement with the finding of, Shirani *et al.* (2002) who reported that adding manure would increase soil hydraulic conductivity. SCM rates of 24 and 36 Mg ha^{-1} increased *Ks* two folds in the non-cultivated soil and only 1.5 folds in the cultivated soil, as compared with the non-amended soil (zero rate of application). The differences among *Ks* values of manure treated soil were remarked although they were not significant. Generally, the *Ks* values were higher in the non-cultivated than in the cultivated soil (13.57 and 8.89 cm h^{-1}, respectively). Addition of SCM promotes the total porosity as the microbial decomposition products of organic manures such as polysaccharides and bacterial gums act as soil particle binding agents (Zhou *et al.* 2013).

Table 2
Effects of SCM on soil bulk density (***BD***) total porosity (***TP***) and saturated hydraulic conductivity (***Ks***) under non-cultivated and cultivated soils.

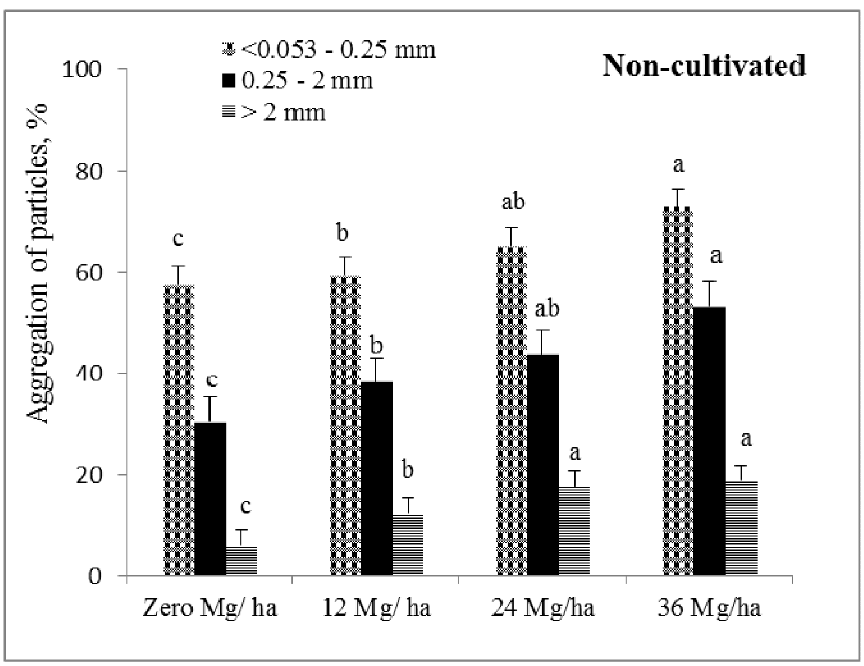
Soils	SCM Mg ha^{-1}	***BD*** (Mg m^{-3})	***TP*** (%)	***Ks*** (cm h^{-1})
Non-cultivated soil	0	1.38a	47.92c	7.49c
	12	1.22b	53.96b	15.06ab
	24	1.16c	56.22ab	15.63a
	36	1.11c	58.11a	16.10a
	Mean	1.22	54.05	13.57
Cultivated soil	0	1.43a	46.03b	6.25c
	12	1.41a	46.79b	9.45ab
	24	1.39ab	47.54ab	9.80a

36	1.35c	49.05a	10.07a
Mean	1.39	47.35	8.89

Note: Values followed by the same letter within a column indicate no significant difference at 0.05 level

These binding agents increase soil porosity and decrease soil bulk density by improving aggregation. SCM application could change the soil density and porosity that consequently change soil hydraulic conductivity. Organic amendments improve these physical properties and consequently improve soil water regime and soil aggregation for crop growth (Shirani et al. 2002 and Bassouny and Chen, 2016).

Soil aggregation was significantly increased with application of SCM in both the non-cultivated and cultivated soils (Figure 1). The increases in the percentage of aggregates varying in within < 0.053 – 0.25 mm in non-cultivated soils were 26.68, 12.98, and 2.94 % recorded for 36, 24 and 12 Mg ha^{-1} treatments, respectively. In the cultivated soil, increased soil micro-aggregates were 3.25, 7.84 and 11.20 % for soils amended with 12, 24 and 36 Mg ha^{-1} respectively, compared with zero Mg ha^{-1}.



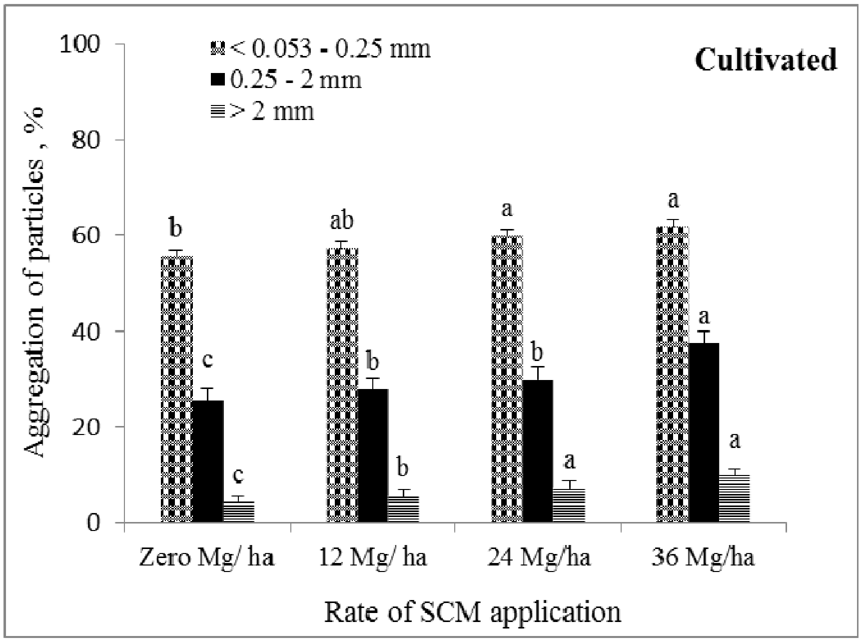


Figure 1
Effect of SCM on aggregation of particles under the non-cultivated soil and the cultivated soil

The SCM application rates of 24 and 36 Mg h^{-1} increased soil small macro-aggregates of particles of 0.25- 2 mm by 43.69 % and 74.76 % for non- cultivated soil, and 17.68 % and 46.95 % for cultivated soil, respectively, when compared with zero treatment. At the cultivated soil, the large soil macro-aggregates particles of > 2 mm were significantly lower at the zero rate (4.35%) and at 12 Mg ha^{-1} (5.70 %) rate than at the 24 Mg ha^{-1} (7.40%) and 36 Mg ha^{-1} (9.95%) rates. The large soil macro-aggregates particles of > 2 mm were significantly higher at rates of 36 Mg ha^{-1} (18.90%) and 24 Mg ha^{-1} (17.80%) in non-cultivated soil compared with 12 Mg ha^{-1} (12.56%) and zero Mg ha^{-1} (6.30 %) treatments.

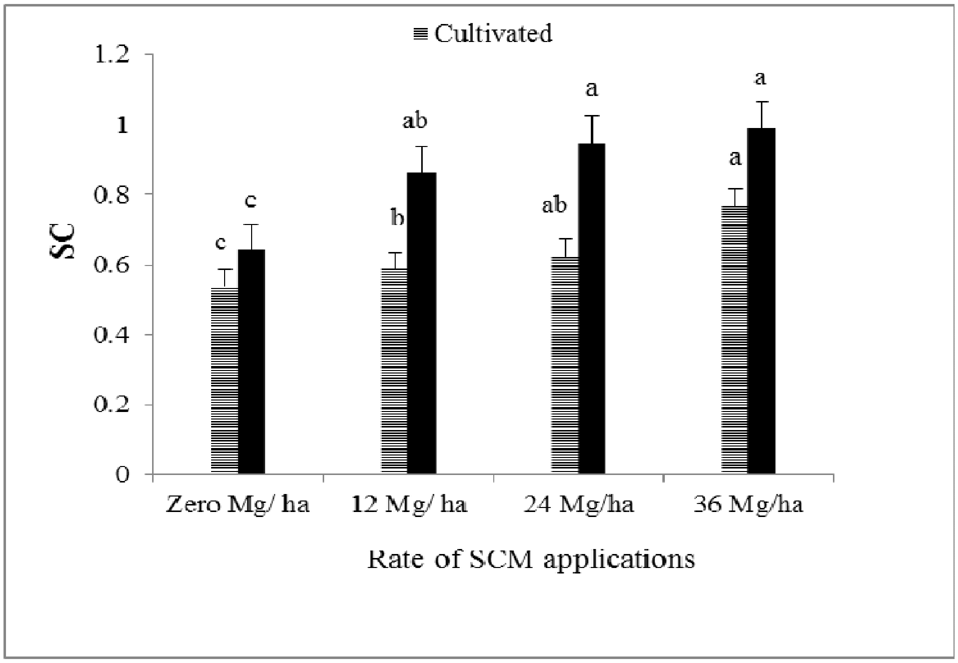


Figure 2
Effect of SCM on soil structure coefficient (SC) under the non-cultivated and the cultivated soils

Figure 1, shows changes in soil aggregation in the soil treated with different rates of SCM as compared to the zero rates. Increasing the rate of SCM application increased soil micro-aggregates of < 0.053 – 0.25 mm, as well as particles of 0.25- 2 mm and particles of > 2 mm ($P < 0.05$). Applying 36 Mg ha^{-1} SCM to the uncultivated and the cultivated soils increased aggregates of particles of >2 mm, 0.25-2 mm and < 0.053- 0.25 mm, when compared to the other treatments.

Application of 24 and 36 Mg ha^{-1} SCM vales increased aggregates of particles< 0.053- 0.25 mm size by twofold in the non-cultivated soil and 1.5-fold in the cultivated soil, compared to the aggregates of particles > 2 mm and 0.25 -2 mm size (Bear *et al.,* 1994). Similar trend of the obtained results was reported by Bronick and Lal*,* (2005). Binding substances produced during organic matter decomposition in soil as well as the products of microbial synthesis caused more aggregation with the soil particles (Shirani *et al.,* 2002; Huang *et al.,* 2010).

Zhang *et al.* (2013) and Zhou *et al.* (2013) found highly significant and positive relations between organic matter content and soil aggregation.

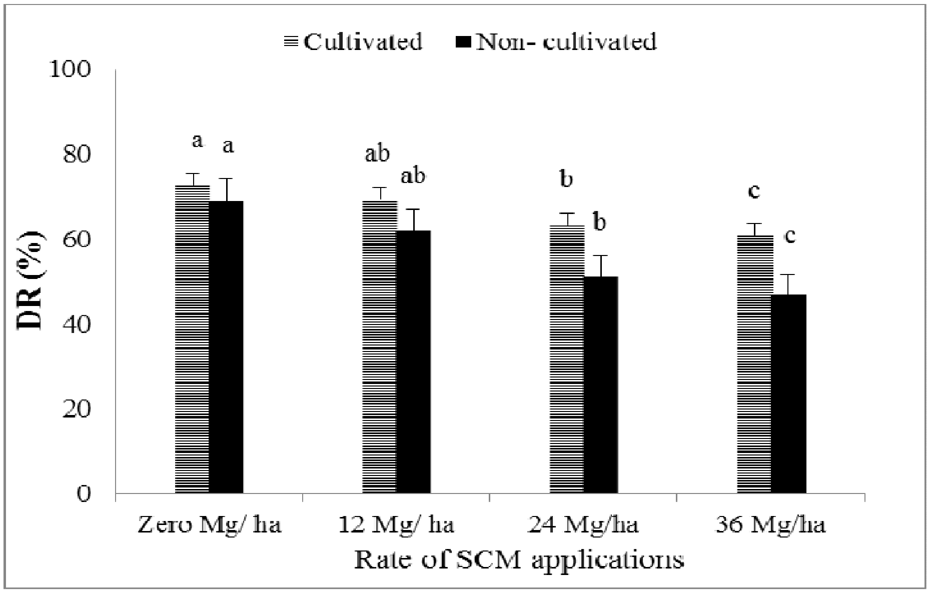


Figure 3
Effect of SCM on dispersion ratio (DR) under the non-cultivated and the cultivated soils

Soil structure coefficient (SC) was significantly increased due to SCM application in both the non-cultivated and cultivated soils (Figure 2). Application of SCM recorded highly significant effect on the SC. The SC was highest in the soil treated with SCM rates, compared with the zero rates. Average SC values were significantly higher in the non-cultivated soil than in the cultivated one (0.85 and 0.62, respectively). Degradation of soil structure due to cultivation was observed with growing potatoes, compared with the non-cultivated soil. However, the SC was increased with increasing the rate of SCM applications. Compared with values in the non-cultivated soil, the results show that SC increased with decreasing number of tubers in 10 kg weight in the cultivated soil. SCM application increased soil organic matter which consequently would improve aggregation and porosity favoring the downward flow of water in soil (Zhang *at el.* 2013).

Dispersion ratio (DR) was significantly decreased due to SCM application in both the non-cultivated and cultivated soils (Figure 3). Application of SCM recorded highly significant effect on the DR. The DR was lowest in the soil treated with SCM at a rate of 36 Mg h^{-1} compared with the other rates. The SCM application rates of 24 and 36 Mg h^{-1} decreased DR by 16.65 % and 21.38 % in the non- cultivated soil, and 2.36 % and 9.38 % in the cultivated soil, respectively, compared with zero rates. The average DR values were significantly lower in the non-cultivated soil than in the cultivated soil (56.15 and 69.97 %, respectively). Therefore, the SCM improved DR in the non-cultivated soil more than the cultivated soil. The effect of organic matter was significant on the DR of clay at 30 cm depth; this clay dispersed as a colloid with a net positive charge, i.e. the point of zero charge of the clay was higher than the pH of the soil. Closer to the soil surface where the organic matter content was greater, the point of zero charge matched the pH of the soil and there was no water dispersible clay (Zhou *at el.,* 2013).Within about 30 cm of the surface of the soil substantial quantities of water dispersible clay were present as the point of zero charge was lowered below the pH of the soil by the absorption of organic matter; therefore, the SCM improved DR in soils (Saman, 2016). Binding substances produced during organic matter decomposition in soil as well as the products of microbial synthesis caused more aggregation with the soil particles (Shirani *et al.,* 2002 and Huang *et al.,* 2010). Zhang *et al.* (2014) and Zhou *et al.* (2013) found highly significant and negative relations between organic matter content and DR.

This effect was more pronounced under low rate of the applied SCM, which further led to increase the compaction around tubers (Omar 1983; Shirani *et al.,* 2002). Pagliai *et al.* (2004) reported that the compacted soils are characterized by a predominance of microaggregates. According to Bear *et al.* (1994), aggregates diameter of 0.25 to 2 mm need to be protected by organic carbon agents otherwise, under heavy and intensive cultivation they would be disrupted.

Potatoes yield increased by SCM application (Table 3) with lower number of tubers in 10 kg weight, which indicated that the organic matter addition produced an increase potatoes yield and decrease tubers numbers. Contents of organic matter showed a positive correlation with aggregate particles of, > 2 mm, 0.25 – 2mm and > 0.053- 0.25 mm whereas it showed a negative one with the DR, which indicates that the organic matter addition increases the soil aggregation and decreased the DR in the same time.

There was a positive correlation ($p< 0.01$) between the number of tubers in 10 kg weight and the DR, indicating that the DR increased with the increase of tuber size; and a negative correlation ($p< 0.01$) with aggregates of >2 mm and > 0.053- 0.25 mm, and ($p< 0.05$) with 0.25- 2 mm, which indicates that the aggregates decreased with the decrease of tuber size. There was a positive correlation between potatoes yield and aggregates of 0.25- 2 mm and > 0.053- 0.25 as well as aggregates of >2 mm and a negative correlation with the DR, which indicates that the organic matter increased potatoes yield and decreased the dispersion ratio. These results are in agreement with those of Gu and Doner, (1993) and Saman, (2016).

Table 3

Effect of SCM on soil organic matter, number of tubers in 10 kg weight and yield potatoes in the cultivated soil

SCM Mg ha^{-1}	Soil organic matter (g kg^{-1})	Number of tubers in 10 kg weight	Potatoes yield (Mg ha^{-1})
0.0	19.50c	124 a	5.5 c
12	21.15ab	102 b	9.0 b
24	22.32a	88 bc	11.0 ab
36	23.36a	78 c	13.0 a

Note: Values followed by the same letter within a column indicate no significant difference at 0.05 level

Tables 3 and 4 indicate that the organic matter in SCM caused a major direct effect on soil aggregation under potatoes cultivation. Such effects were more pronounced with application of the higher rates of SCM. Similar results were reported by Shirani et al. (2002). Such increase in soil aggregation as well as protection of aggregates from destruction by compaction was shown in the cultivated soil. The above mentioned results may lead to the conclusion that suitable manuring rate at 24 and 36 Mg ha^{-1} is a major factor of protecting aggregation from destruction.

Table 4

Correlation coefficients (r) among aggregates of particles, dispersion ratio (DR), soil organic matter, number of tubers in 10 kg weight and potatoes yield in the cultivated soil

	> 2 mm	0.25-2mm	< 0.053-0.25mm	DR
Soil organic matter (g kg^{-1})	0.95**	0.85**	0.96**	-0.86**
Number of tubers in 10 kg weight	-0.92**	-0.77*	-0.93**	0.83**
Potatoes yield (Mg ha^{-1})	0.65*	0.80**	0.93**	-0.85**

Note: *, **Significant at p< 0.05 and p< 0.01, respectively

4. CONCLUSIONS

Application of solid cattle manure improves soil macro and micro-aggregates through associated increases in organic matter. Effect on aggregate structures may be quite different. The SCM increased soil porosity, and saturated hydraulic conductivity while decreased bulk density via increasing aggregation in the non- cultivated soil compared to the cultivated one. The dispersion ratio decreased by SCM applications particularly in the non-cultivated than in the cultivated soil. The SCM increased soil structure coefficient in the non- cultivated compared to the cultivated soils. Organic matter showed a positive correlation with aggregation of particles and, on the other hand, a negative correlation with the dispersion ratio, indicating that the organic matter caused increase soil aggregation and decrease in the dispersion ratio. Application of solid cattle manure at a rate of 24 and 36 Mg ha^{-1} was the most effective management practice to improve the soil aggregation against destruction.

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