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

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

Manure application is important for maintaining and improving soil quality and aggregation. Two field experiments were carried out on a silty clay loam soil during the two successive summer seasons of 2016 and 2017 to examine the influence of solid cattle manure (SCM) 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. The first was designed to study the effect of SCM on soil aggregation (non- cultivated soil), and the second was to study the effect of SCM added to the grown potato on soil aggregation (cultivated soil). Four rates of SCM were added to the soil before tilth: 0, 12, 24 and 36 Mg ha^{-1}. The SCM application significantly ($P < 0.05$) affected soil physical properties after 2 years application. Soil porosity and saturated hydraulic conductivity increased, while bulk density decreased 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 significantly ($P < 0.05$) increased by the application of SCM. The application of SCM decreased significantly the dispersion ratio. The 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-

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aggregates under potato 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. The strong positive correlation was between the number of tubers and dispersion ratio, as well as between potato yield and soil aggregation, which indicated that the organic matter addition increased the potato yield and decreased the dispersion ratio. In conclusion, the SCM improved soil aggregation and dispersion ratio in cultivated and non-cultivated soils with increase potato yield.

Keywords: Macro-aggregates; micro-aggregates; dispersion ratio; structure coefficient; hydraulic conductivity; bulk density; solid cattle manure; potato yield.

1. INTRODUCTION

The application of animal manure to agricultural lands has been viewed as an excellent strategy to recycle nutrients and organic matter that can support crop production and maintain or improve soil quality [1]. Generally, soil organic matter and biological activity increase, and some soil physical properties improve following manure applications. Aggregation is perhaps one of the most important stable soil aggregates that have a beneficial influence on soil physical properties affected by organic matter additions due to improving moisture status and nutrient dynamics, maintaining soil tilth, and soil reducing erosion [2]. Thus, incorporation of animal manure into the soil alleviates the negative effects and improves soil aggregation.

Solid cattle manure (SCM) is an excellent soil amendment capable of increasing soil quality. Many studies have shown that balanced application of organic fertilizers can increase soil organic carbon and maintain soil productivity [3], either directly through supplying nutrients or indirectly through modifying soil physical properties that can improve the root environment and stimulate plant growth [4]. Organic applications to soils increase organic matter content of soils, which can bind soil particles, forming aggregates. This can improve soil structure and favors increasing the downward flow of water into soils [5]. The application also increases soil porosity, pore size distribution and saturated hydraulic conductivity and reduces bulk density [6,7]. Overall, physical, chemical and biological properties of the soil could be improved by organic fertilization [8].

Soil structure is defined as the size and arrangement of particles and pores in soils [9]. 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 [10]. A desirable range of pore sizes for a tilled layer occurs when most of the clay fraction is flocculated into micro-aggregates, defined as < 0.25 mm in diameter, and secondly these micro-aggregates and other particles are bound together into macro-aggregates > 0.25 mm in diameter [11].

Soil aggregation is a key indicator of good soil quality since it increases water and nutrient retention, and offers suitable habitats for microbial activity [12]. Aggregations have been studied by Zhang and Peng [13] and Huang et al. [14] who stated that the internal microstructure of aggregates can provide information regarding soil aggregation processes and soil quality. Water stable aggregates are major factors that influence soil productivity. Formation, size and stability of aggregates are affected by physical, chemical and environmental conditions [15,16] that are directly affected by organic matter application [17].

Tuberculous crops have a significant effect on soil aggregation and dispersion ratio, particularly in potato cultivations. Potato (*Solatium tuberosun* L.) is one of the major world food crops. It is an economical food that 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 nutrients and increase soil organic matter and the overall soil productivity [18]. Omar [19] found that stability of aggregates after potato cultivation is less than after clover, cotton or maize cultivations and that the size of aggregates after potato cultivation was smaller. Organic fertilizers have a significant effect on soil aggregation and dispersion ratio under potato production, particularly at high rates [20].

Many soil physical, biological and chemical properties are affected by climate condition. The northern of Egypt has a cold semi-arid climate and there is limited documentation on the impact of organic matter on soil properties. Most soils of Egypt are vulnerable to compaction, crusting and erosion because of unstable aggregates. The main objective of the current study was to assess the effect of solid cattle manure on macro and micro-aggregates, dispersion ratio and soil structure coefficient as well as physical properties.

2. MATERIALS AND METHODS

2.1 Characterization of Study Site

This study was conducted in Sidie Salim District, Kafr El-Sheikh Governorate, northern Egypt (31°27′N, 30°79′E), and 10 meters above sea level. The climate of the study area is arid to semi-arid and is 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 and in winter is 13.2°C. Wind is generally western and north westerly.

Soil sampled was taken before the experiment started in December 2015 (0-30 cm soil depth). Soil texture (USDA) is a silty clay loam having 5.08% coarse sand, 10.0% fine sand, 51.80% silt and 33.12% 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 (1: 2.5 soil: water suspension). Solid cattle manure was taken from a local animal feedlot farm. Main properties of the solid cattle manure are shown in Table 1.

2.2 Treatments and Experimental Design

Two field experiments were designed to study the effect of solid cattle manure (SCM) on soil aggregation and dispersion ratio (under non-cultivated and cultivated soil with potato) during the two successive summer seasons of 2016 and 2017. 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). The SCM was added to the soil before tilth at four rates i.e. 0, 12, 24 and 36 Mg ha^{-1}. The SCM was mixed with soil fifteen days before planting. Plots were planted in the summer season of January 4^{th} and the harvest was on April 5^{th}, 2016 and 2017. Potato tubers (*Solatium tuberosun L.*) cv. Lady Rosetta were planted in prepared plots having 25 cm apart between each two successive hills. Each plot 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 [21]. 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 0.25-2 mmϕ), and micro-aggregates (Ag 0.053- 0.25 mmϕ) expressed as g 100 g^{-1} of dry soil [22].

Table 1. Main properties of solid cattle manure (SCM) applied to the soil

Properties	Unit	Value
pH (1:10 SCM : water)	- log [H^+]	7.51
EC (1:10 SCM : water)	dS m^{-1}	2.71
Organic matter	g kg^{-1}	224.50
Moisture content	%	17.61
Bulk density	Mg m^{-3}	0.401
Total N	g kg^{-1}	4.43
Total P	g kg^{-1}	5.22
Total K	g kg^{-1}	11.88

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 [23]. The DR was then calculated according to the following equation:

$$DR = \frac{\mathcal{S}c\mathcal{W}}{\mathcal{S}c\mathcal{A}} \times 100 \qquad (1)$$

Where $\mathcal{S}c\mathcal{W}$ is the percentage of "silt +clay" without dispersion while $\mathcal{S}c\mathcal{A}$ is the percentage of "silt+ clay" after dispersion.

Soil structure was evaluated by the structural coefficient of Shein et al. [24]; the structure coefficient (*SC*) is calculated as:

$$SC = A \div B \qquad (2)$$

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. Total soil porosity (TP) was calculated from bulk density and average particle size density (2.65 Mg m^{-3}). Each plot was also sampled by the cylinders three times (replicates) to measure the saturated hydraulic conductivity (Ks) in the laboratory using the constant-head method [25]. Soil texture was determined by the pipette method [26]. Organic matter was evaluated by using the modified Walkely and Black method [27]. The pH, EC and total forms of N, P and K were also estimated according to Rowell [28].

2.4 Statistical Analysis and Data Processing

Data were all statistically analyzed using analysis of variance (ANOVA) at a 0.05 level, with the help of SPSS19.0 for Windows (SPSS Inc., Chicago, USA). A correlation matrix of different properties was based on the linear correlation coefficients ($p < 0.05$ and $p < 0.01$).

3. RESULTS AND DISCUSSION

After 2 years application of solid cattle manure (SCM), there was a significant effect ($P < 0.05$) on soil physical properties. The SCM application decreased significantly the value of soil bulk density (BD) in the non-cultivated soil (Table 2). 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 cultivated soil decreased the BD by 2.87 to 5.59%, respectively, compared with zero treatment. On the other hand, application of the SCM 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. [6] and Yang et al. [7]. The BD values in the non-cultivated soil were significantly lesser than those of the cultivated soil. This reflects a great effect of tubers density on the soil BD in the cultivated soil 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). The SCM increased directly soil organic matter leading to an 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 [16].

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. [16] who reported that adding manure would increase soil hydraulic conductivity. The 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 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 [11].

These binding agents increase soil porosity and decrease soil bulk density by improving aggregation. The 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 [16,4].

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

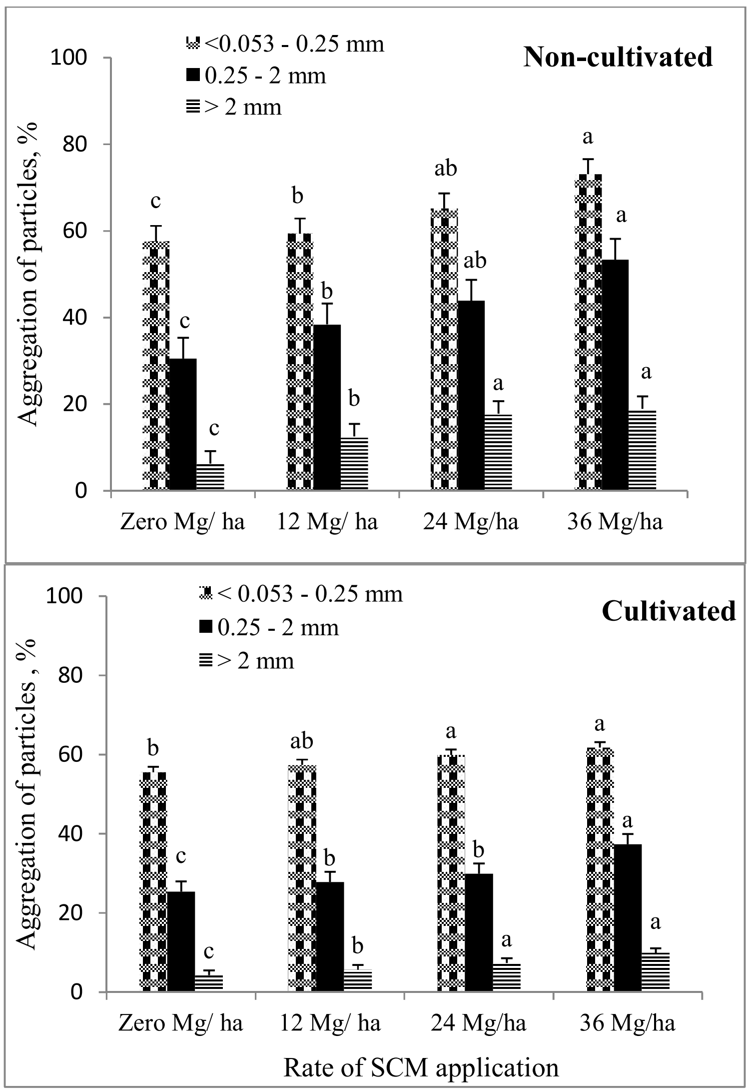

Fig. 1. Effect of SCM on aggregation of particles under the non-cultivated soil and the cultivated soil. Vertical bars indicate mean ± 1 standard error

Soil aggregation was significantly increased with the application of SCM in both the non-cultivated and cultivated soils (Fig. 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}.

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.

Fig. 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 increased aggregates of particles< 0.053- 0.25 mm size by two folds 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 [29]. Similar trend of the obtained results was reported by Bronick and Lal [10]. Binding substances produced during organic matter decomposition in soil as well as the products of microbial synthesis caused more aggregation with the soil particles [14,16]. Zhang et al. [5] and Zhou et al. [11] found highly significant and positive relations between organic matter content and soil aggregation.

Soil structure coefficient (SC) was significantly increased due to SCM application in both the non-cultivated and cultivated soils (Fig. 2). 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 potato, 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. The SCM application increased soil organic matter which consequently would improve aggregation and porosity, favoring the downward flow of water in soil [1].

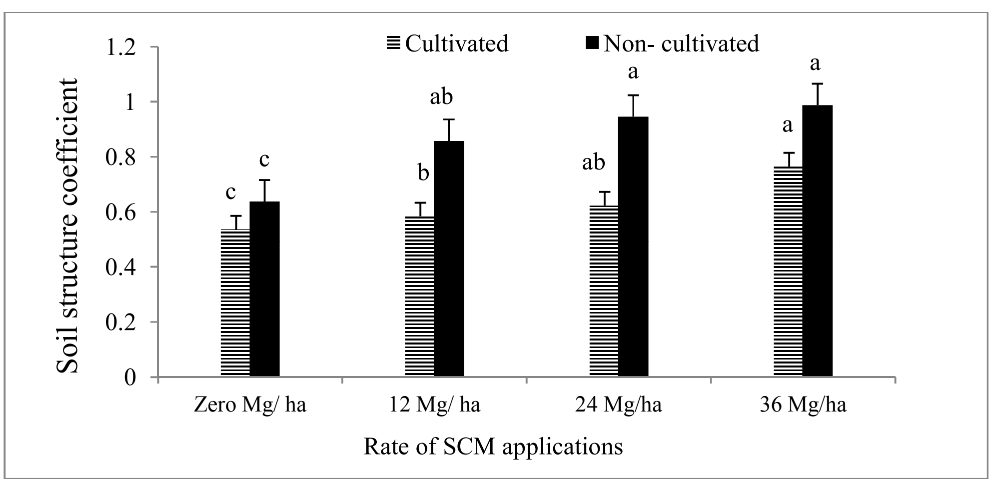

Fig. 2. Effect of SCM on soil structure coefficient under the non-cultivated and the cultivated soils. Vertical bars indicate mean ± 1 standard error

Dispersion ratio (DR) was significantly decreased due to SCM application in both the non-cultivated and cultivated soils (Fig. 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 [11]. 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 [30]. Binding substances produced during organic matter decomposition in soil as well as the products of microbial synthesis caused more aggregation with the soil particles [14,16]. Zhang et al. [1] and Zhou et al. [11] 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 [19]. Pagliai et al. [17] reported that the compacted soils are characterized by a predominance of microaggregates. According to Bear et al. [29] 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.

Potato 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 potato yield and decrease tubers numbers. Contents of organic matter showed a positive correlation with aggregate particles of, > 2 mm, 0.25 - 2 mm 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 potato 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 potato yield and decreased the dispersion ratio. These results are in agreement with those of Gu and Doner [31] and Saman [30].

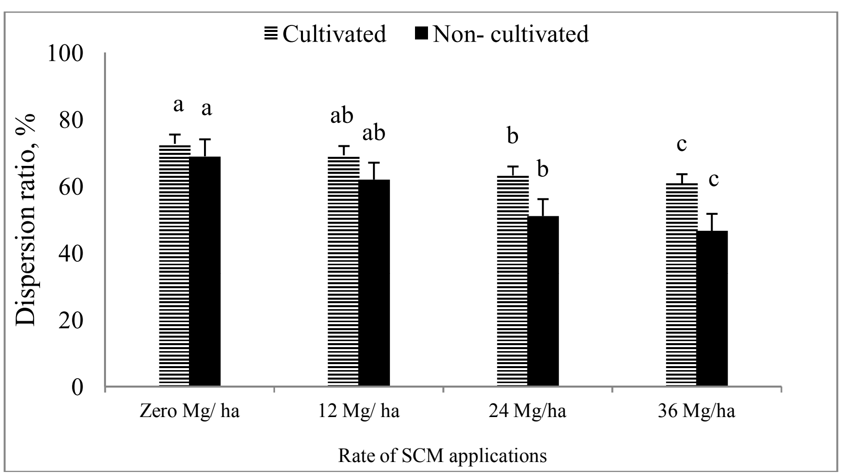

Fig. 3. Effect of SCM on dispersion ratio under the non-cultivated and the cultivated soils. Vertical bars indicate mean ± 1 standard error

Table 3. Effect of SCM on soil organic matter, number of tubers in 10 kg weight and potato yield in the cultivated soil

SCM Mg ha^{-1}	Soil organic matter (g kg^{-1})	Number of tubers in 10 kg weight	Potato yield (Mg ha^{-1})
0.0	19.50c	124 a	5.5 c
12	20.15ab	102 b	9.0 b
24	21.32a	88 bc	11.0 ab
36	22.36a	78 c	13.0 a

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

Table 4. Correlation coefficients among aggregates of particles, dispersion ratio (DR), soil organic matter, number of tubers in 10 kg weight and potato yield in the cultivated soil

	> 2 mm	0.25-2 mm	< 0.053-0.25 mm	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**
Potato yield (Mg ha^{-1})	0.65*	0.80**	0.93**	-0.85**

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

Tables 3 and 4 indicate that the organic matter in SCM caused a major direct effect on soil aggregation under potato cultivation. Such effects were more pronounced with application of the higher rates of SCM. Similar results were reported by Shirani et al. [16]. 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 or 36 Mg ha^{-1} is a major factor of protecting aggregation from destruction.

4. CONCLUSIONS

Application of solid cattle manure for two successive years improved 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 soil 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 or 36 Mg ha^{-1} was the most effective management practice to improve the soil aggregation against destruction.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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