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Effect of tillage systems and plant residues on whole soil stability and normalized stability indices

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Abstract

Tillage is one of the important management tools, and it may affect soil structure. In this research, the effect of 3 tillage systems including conventional (CT), minimum (MT) and no tillage (NT) together with crop residues of 0, 30 and 60 percentage on stability of soil structure was studied. This research was performed as a randomized complete blocks design in three replications at Khorasan Razavi province (Iran) for a rotation of 4 years (wheat, canola, wheat, tomato). The whole soil stability (WSSI), and normalized stability indices (NSI) were determined. The results showed that indicators of soil structure were influenced by management practices (plant residues and tillage), and they were significantly decreased by increasing tillage intensity, while NT and MT improved soil structure stability indicators significantly compared to the CT due to increasing the soil organic matter. The mean of WSSI in NT was 9 and 64% more than the MT and CT systems, respectively. Also, the average of NSI in NT was 9 and 95% greater than the MT and CT systems, respectively. Also, among different aggregate size classes, 2-9.5 mm aggregate size had the highest WSSI values in all treatments. In general, the values of WSSI and NSI were NT > MT > CT. In addition, among studied treatments in terms of soil structure stability, NT with 60% of residues was the best treatment and CT with no residues was the worst one. Therefore, the conservation tillage is recommended to increase stability of soil structure and to prevent land degradation.

Keywords: Aggregation, soil management, tillage, normalized stability index, whole soil stability index

Introduction

Soil management and tillage operations are the main components of sustainable agriculture. Soil structure is one of the most important physical property which is influenced by tillage operations. Description of the soil structure such as size, form and soil secondary particles stability are important because of their effect on most of the environmental and agricultural processes (Diaz-Zorita *et al*., 2002). The soil structure is often measured by the soil aggregates stability (Six *et al*., 2000; Bronick and Lal, 2005). Soil structure affects many characteristics such as air and water movement, temperature and movement of the nutrients and distribution of pores in soil (Farahani *et al*., 2018a, 2018b; Zaker and Emami, 2019). Soil attributes such as aeration, water holding capacity, availability of nutrients and organic matter, and soil biological activity are influenced by soil aggregation (Six *et al*., 2004; Ranjbar *et al*., 2016), too. Seed germination and the crop root growth as well as decomposition of the soil carbon are mainly dependent on the soil structure (Denef *et al*., 2004, Annabi *et al*, 2007; Nabavinia *et al*., 2015; Gholoubi *et al*., 2019). Soil erosion is also influenced by soil structure (Amiri khaboushan *et al*., 2017; Shahab *et al*., 2018). Also, soil structure has a significant effect on carbon storage due to storage potential inside the aggregates and physical properties (Gholoubi *et al*., 2018).

Low soil organic matter and poor soil physical properties and conventional tillage led the farmers' tendency to conservation tillage methods (Miqdad *et al*., 2013). Soil aggregate stability is very useful to assess the effects of land use and management of erosion control (Cerda, 2000). Soil management including minimum tillage has often been found to improve soil structure (Oyedelem *et al*., 1999), and soil aggregates are more stable under minimum tillage compared with conventional moldboard tillage (Pagliai *et al*., 2004). The higher stability under minimum tillage than conventional tillage has also been reported in spring and summer in literature (Kushwaha *et al*., 2001; Eynard *et al*.,

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2004). Ramezani *et al*. (2012) reported that decreasing the number of tractor trains in the soil, increased the amount of porosity and coarse aggregates. Czys and Dexter (2009) found that tillage practices reduced the size of aggregates. Shaver *et al*. (2003) reported that increasing the biodegradation of plant residues in the soil increased the coarse aggregates, especially at 2.5 centimeters of soil surface. Six *et al*. (2000) reported that in agricultural systems, the amount of coarse aggregates was little.

Cultivation can cause destruction of soil aggregates and the loss of organic carbon (Kay, 1990). Watts and Dexter (1997) found that management practices in the long run reduced soil organic matter and the stability of aggregates. In Morocco, the no-tillage system compared with conventional tillage improved soil quality, organic matter content, aggregate stability and nutrient content in the soil (Mrabet, 2002). Lebron *et al*. (2002) concluded that the culture system has an important effect on stability of aggregate and aggregate size distribution. Sparrow *et al*. (2006) investigated the long-term effects of tillage systems and management of plant residues on soil properties and found that low-intensity tillage practices increased organic and inorganic materials and also maintained soil moisture. Mc Cool *et al*. (2008) found that plowing and burning the crop straw reduced the mean weight diameter of aggregates and the sum of the pores larger than 60 micrometers. Kayode *et al*. (2009) reported a significant decrease in soil structure stability, saturated hydraulic conductivity, and water infiltration rate in soil after burning of plant residues. Bhattacharyya *et al*. (2009) found that conservation tillage systems significantly increased the mean weight diameter of aggregates. Increasing the geometric mean diameter of aggregates was related to increasing the soil organic matter (Zhang *et al*., 2007).

Increasing soil density and erosion, as a result of continuous cultivation of row crop and intensive tillage, is the concern and warrants more attention to conservation tillage. If this method is associated with the proper management of crop residues, it can be considered as an effective strategy in preventing soil erosion, reducing air pollution, energy consumption and costs in agriculture. The effects of tillage operations on soil structure have been well documented, and previous studies focused mainly on the aggregate stability (Emami *et al*., 2012). However, stability of aggregate is usually measured on a specific aggregate size class that is not a measurement of whole soil structure, (Six *et al*., 2000). The responses of soil structure indicators especially WSSI and NSI on a rotation of 4 years (wheat, canola, wheat, tomato) is not known in semi-arid area such as Khorasan Razvi province of Iran. Therefore, it is needed to assess the effects of management practices on WSSI and NSI to assess their alteration for a rotation of 4 years in semi-arid area. The objectives of the present study were to investigate the effects of tillage systems and crop residues during a rotation of 4 years (wheat, canola, wheat, tomato) on WSSI and NSI.

Materials and Methods

Study area

The study area is located at Agricultural Research Center of Khorasan-Razavi (Iran) in a loamy soil. The latitude and longitude were 59 ° 37' E and 36 ° 12' N, respectively, with a total area of 220 hectares. The average altitude of this site is 1010 m, the mean of annual rainfall and temperature is 260 mm and 13.5 °C, respectively. The physiographic unit of this station is slope alluvial plain and its soil is classified in two orders of entisols and aridisols (Zangi Abadi, 2016). The slope of this site was 0-3%.

Sampling and preparation for the treatments

The effect of 3 tillage systems including 1) conventional tillage, CT (plowing + disc + leveling + furrowing + seed cultivation), 2) minimum tillage, MT (disc + furrowing + seed cultivation) and 3) no tillage, NT (seed cultivation) with crop residues of 0, 30 and 60% on stability indicators of soil structure was studied during 4 years from 2011 to 2015. Plant residues were applied on soil surface after harvesting them in September every year. In no tillage system, a disk or cyclotiller was used and seed cultivation was carried out at a single stage. In conventional system, soil tillage was carried out by moldboard plough. The plant rotation was wheat, canola, wheat, tomato, wheat. The research was conducted as a randomized complete blocks design with three replicates. Plant residues were applied on soil surface after harvesting them in September every year. After 4th year, soil samples were collected from soil surface (0-15 cm depth) in December 2015 and soil structural indicators i.e. WSSI and NSI were measured.

Whole soil stability index (WSSI)

Distribution of aggregate size and stable aggregates of dry-sieved were measured in 4 size classes (0.053-0.25, 0.25-1, 1-2 and 2-9.5 mm). For dry sieving the aggregates were placed on screen size of 9.5 mm, shaken gently at least 50 times to pass through the screen, and in each size class weight of aggregates was individually measured. Water stable aggregates (WSA) in 4 subsamples from each aggregate size were measured based on the modified method of Kemper and Rosenau (1986). The distribution of dry aggregates and WSA were used in Eq. 1 for calculating the WSSI (Nichols and Toro, 2011).

$$WSSI = \left[\sum_{i}^{n}[(I) \times (Pai) \times ((WSAi) \div 100)\right] \div n \quad (1)$$

Where P_{ai}, and WSAi are the proportion of dry-sieved aggregates and Water stable aggregates for each size class i, respectively, and n is the number of the aggregate size classes, i=n and by an increase of 1 from the largest to the smallest aggregate size class it decreases.

Normalized stability index

The normalized stability (NSI) is compared to the distribution of aggregates before and after disruption (Six *et al*., 2000). NSI was measured on soil samples taken from the conventional, minimum, and no tillage systems with crop residues of 0, 30 and 60 percentage treatments. In this study, the size classes used included i= 1 ≤ 0.053 mm, i = 2 = 0.053-0.25 mm, i= 3 = 0.25-2 mm, i = 4 ≥ 2000 mm to determine NSI. The NSI was calculated as (Six *et al*., 2000):

$$NSI = 1 - [DL/DL(max)] \quad (2)$$

DL is the whole soil disruption level and it was calculated as:

$$DL = 1/n \sum_{i}^{n}[(n+1) - I] \times DLSi \quad (3)$$

where n is number of aggregate size classes. The maximum disruption [DLS_i (max)] was calculated based on Eq. 4:

$$DLSi = \frac{[(Pi0 - Pp) + |(Pi0 - Pp)|]}{2} \times \frac{[1]}{[Pi0 - Si0]} \quad (4)$$

Pp, and P_{io} are sand content after the whole soil was completely disrupted, and proportion of total sample weight in size class i before disruption, respectively.

Finally, Statistical analyses were made using the SPSS software. Mean comparison with LSD method was performed at the level of 0.05.

Results and Discussion

Proportion of dry-sieved aggregates

No-tillage and minimum-tillage treatments had the highest proportion of dry-sieved aggregates (>2 mm, Fig. 1). In CT treatment, addition of plant residues slightly increased the Pai, and in conservational treatments (MT and NT) the plant residues slightly reduced the Pai. Bonding the soil particles in conservation tillage systems increased due to less disturbance and as a result of this, formation of macro aggregates increased. It seems that in CT system the role of organic matter (plant residues) to create the macro aggregates is more important, while in NT and MT systems the role of compaction and tractor trains is more important. In fact, the less tractor trains in conservation tillage systems is corresponding for the formation of macro aggregates. In addition, in CT system mixing the plant residues into soil increased the organic carbon. As a result of this, soil particles flocculated and macro aggregates slightly increased, while in MT and especially in NT systems, plant residues often remained on soil surface. The Pai values of aggregates smaller than 2 mm in CT treatments were greater than NT and MT. It seems that breakdown of macro aggregates due to compaction as a results of tractor trains led to micro aggregates increase. Zhang *et al*. (2007) attributed the main reason for increasing the aggregation to the soil organic matter content. The organic carbon produced by the decomposition of plant residues acts as a cementing agent, which leads to the accumulation of the primary particles of the soil and the formation of stable aggregates. Nicholas and Toro (2011) reported the coarse aggregates in no tillage systems, native rangeland and medium grazing rangelands. Angers (1998) also found that the amount of aggregates in a non-tillage system was about 30% higher than conventional tillage. The most Pai in the size class > 2 mm (large aggregates) was assigned to no tillage and then to the minimum tillage as a results of less tillage practices. The Pai values in the other size classes (< 2 mm) were not considerably different (Fig. 1). The results of Pai indicated that management practices through less tillage, and plant residues increased the formation of macro aggregates. Nicholas and Toro (2011) reported that the highest water stable aggregates in classes 0.25-1, 1-2 and > 2 mm obtained in zero and minimum tillage systems. Bronick and Lal (2005) showed that soils with natural cover crops had significantly more agglomerated and more stable aggregates than cultivated soils, which could be due to higher microbial mass, debris and plant roots, polysaccharides and humic materials in coarse aggregates (Balabane and Plante, 2004).

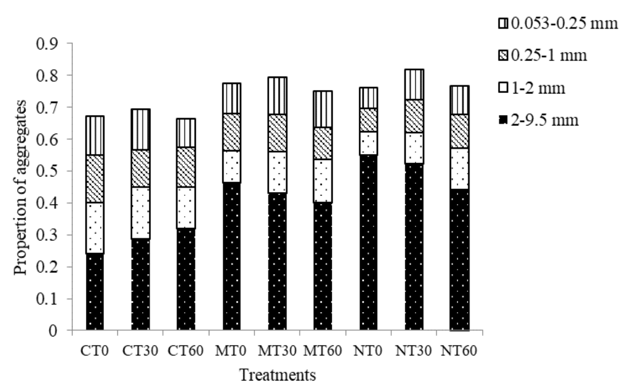

Figure 1: The proportion of dry-sieved aggregates for each size class in different treatments (Conventional tillage (CT), Minimum tillage (MT) and No tillage (NT), 0, 30 and 60 represent percent of plant residues)

Water stable aggregates (WSA)

No and minimum tillage treatments had the highest abundance of coarse aggregates stable in water (> 2 mm). The application of conservation tillage methods, due to less disturbance by plowing, is a reason to increase the porosity and the bonding of soil porosity due to the formation of water stable aggregate. Addition of plant residues increased the WSA for all aggregate sizes in NT tillage systems, while In CT and MT this trend was found only for medium (0.25-1 mm) and fine aggregates (< 0.25 mm). This result may be due to vulnerability of macro aggregates against mechanical forces of train tractors, which due to plowing and soil compactness, the stability of macro aggregates decreases, while in NT treatments 4 years was enough for formation and stability of macro aggregates. Therefore, it seems that the role of soil compaction in stability of macro aggregate is greater than the organic matter. As it is shown in Fig. 2, the abundance of water stable aggregates in NT and MT treatments with 0% of the residues were considerably higher than CT with 0% residues. Some researchers have mentioned that the long-term use of conservation tillage is a factor to increase the porosity and coherence of soil porosity and formation of water stable aggregates (Beare *et al*., 1994; Jabro *et al*., 2009; Garcia-Orenes, 2012). Nicholas and Toro (2011) found greater coarse stable aggregates in treatments with no tillage operations, such as unused pastures and medium grazing rangelands. Angers (1998) also found that the stable aggregates in a non-tillage method was about 30% higher than conventional tillage. On the other word, Zhang *et al*. (2007) attributed the main reason for increasing the water stable aggregate in such treatments to the organic matter content due to the mixing of residues into the soil. Positive correlation between sustainability of aggregates and the amount of soil organic matter was obtained by Blanco-Canqui *et al*. (2006). Therefore, the greater values of WSA for aggregates smaller than 1 mm in treatment receiving organic matter may be due to addition of organic matter. These results are supported by data of organic matter, because the amounts of organic matter in conservational tillage systems were significantly greater than the conventional tillage system (Fig 5).

Whole soil stability index (WSSI)

In all treatments, the highest whole stability index was related to the particle size class > 2 mm, and among the tillage treatments the highest WSSI of these aggregates was found in the conservational tillage system due to less disturbance by plowing and the lowest WSSI of these aggregates was found in the conventional tillage system (Fig. 3). Also, no-tillage treatments showed a greater amount of WSSI than the minimum tillage system. The average WSSI in the size class > 2 mm in NT was 11% and 141% higher than MT and CT systems, respectively. Also, there was no considerable difference between the two conservation systems i.e. NT and MT systems. The highest WSSI value in size class of > 2 mm in NT system is due to a less tillage practices. Similar to the results of this research, Bronick and Lal (2005) indicated that coarse aggregates were the most sensitive components of soil structure to environmental, climate and management changes. Herrick *et al*. (2001) reported that aggregates > 0.25 mm were more influenced by management practices and land use. Therefore, tillage reduced the WSSI in this research.

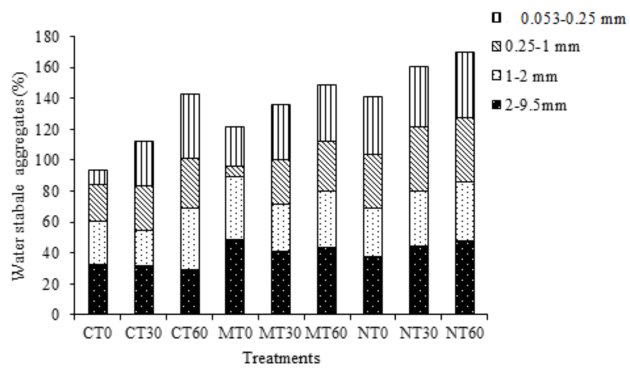

Figure 2: The water stable aggregates for each size class in different treatments (Conventional tillage (CT), Minimum tillage (MT) and No tillage (NT), 0, 30 and 60 represent percent of plant residues)

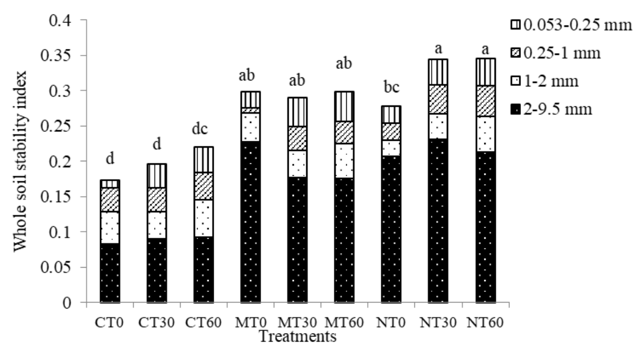

Figure 3: The whole soil stability index for aggregate size classes in different treatments (Conventional tillage (CT), Minimum tillage (MT) and No tillage (NT), 0, 30 and 60 represent percent of plant residues)

A significant difference was found between different tillage systems for WSSI ($p \leq 0.05$). The WSSI results indicated that the NT had the highest value of WSSI, and the CT had the lowest WSSI value (Fig. 3). The average of WSSI in no tillage treatment was 9 and 64% higher than minimum and conventional tillage treatments, respectively and WSSI decreased due to tillage operations, because tillage is the most destructive force of the soil structure (Beata *et al*., 2005; Alvaro-fuents *et al*. 2008). Nicholas and Toro (2011) reported that due to management practices the WSSI was different. Addition of plant residues had no considerable effect on WSSI of coarse size (> 2mm) in all treatments, while it slightly increased the WSSI of size class smaller than 2 mm, therefore it seems that coarse size of WSSI as well as Pai and WSA, was less influenced by organic matter and coarse size of WSSI due to less plowing and consequently compactness in NT and MT are dominant. Totally, because the WSSI of size classes of smaller than 2 mm increased in treatment receiving organic matter, the value of WSSI as a result of plant residues increased significantly in NT (Fig. 3). In MT treatments, addition of plant residues had no significant effect on WSSI. In CT treatments, addition of the plant residues increased WSSI, but it was not significant. Among the studied treatments, the highest and lowest values of WSSI were found for NT with 60 and 30% residues (0.38, and 0.36, respectively) and CT with 0% (0.17) residues, respectively. The average of WSSI in NT with 60% plant residues was 98% higher than CT with no plant residues. These results are similar to the organic matter. According to Fig. 5, the amounts of organic matter in conservational tillage system were significantly more than conventional tillage system.

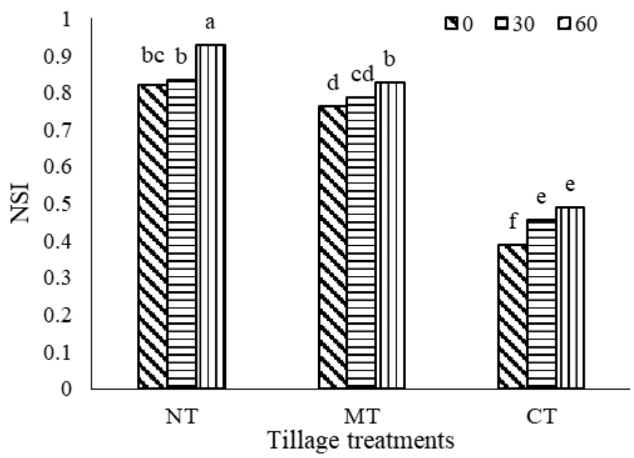

Figure 4: Effect of tillage treatments and plant residues on normalized stability index (Conventional tillage (CT), Minimum tillage (MT) and No tillage (NT), 0, 30 and 60 represent percent of plant residues)

Normalized stability index (NSI)

NSI values decreased with increasing tillage intensity and its order was NT> MT> CT (Fig. 4). The average of NSI in no tillage treatment was 9 and 95% higher than the minimum and conventional tillage systems, respectively. NT and MT systems with less tillage operation practices and compactness which it in turn improved the stability of aggregates and the NSI. Low stability of aggregates in CT may be due to high soil plowing and breakdown of the aggregates during tillage operations. Six *et al*. (2000) found that the NSI decreased with increasing tillage intensity, so that it was arranged in the order of native plants> NT>CT. In NT and MT treatments, by addition of 60% of plant residues, the amount of NSI significantly increased compared to the control, and the difference between 0 with 30% of plant residues was not significant. In CT, addition of the plant residues significantly increased the NSI. In this treatment, the difference between 30 and 60% of plant residues was not significant.

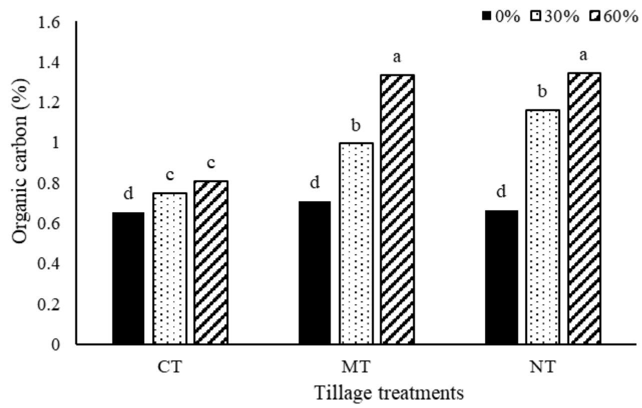

Figure 5: Effect of tillage treatments and plant residues on organic carbon content (Conventional tillage (CT), Minimum tillage (MT) and No tillage (NT), 0, 30 and 60 represent percent of plant residues)

Mixing plant residues into soil is one of the management methods that by increasing the organic carbon content can improve the soil physical and structural properties. Listrom *et al*. (2001) cited that 58% of plant residues should be remained in order to produce stable soil structure. Application of proper methods of tillage and plant residues can be an effective step in improving the soil physical characteristics and achieving sustainable agriculture. Beare *et al*. (1994) expressed that the tillage method severely affected the amount of organic matter, and no-tillage methods or conservation tillage increases the amount of organic matter in the soil. Therefore, one of the possible reasons for increasing the soil structure stability indicators in conservation tillage systems is increasing the organic carbon, and subsequent microbial population microbial activity, the metabolites produced by them, such as polysaccharides. In other words, any decrease in the amount of soil organic matter can have the adverse effect on stability of soil structure (Mrabet, 2002). Long-term use of crop rotation causes an increase in mean weight diameter of aggregates (Karami *et al*. 2012). Increasing the tillage operation by reducing the organic carbon of the soil decreases the stability of aggregates and decreases the stability of the soil structure. The results of NSI are supported by data of organic matter, because the amounts of organic matter in conservational tillage systems (no tillage and minimum tillage) were significantly more than conventional tillage system (Fig 5), therefore increasing the organic matter led to increase NSI.

Conclusions

Soil structure is an important property that affects other aspects of soil, such as erosion, movement of air and water, and infiltration rate etc. Improvement in the soil structure in order to achieve sustainable agriculture requires the proper management of plant residues and tillage operations. In this research, the effect of management operations (tillage and plant residues) on indices of soil structure i.e. NSI, and WSSI was investigated at the research center of Khorasan Razavi province (Iran) for a rotation of 4 years (wheat, canola, wheat, tomato). According to the results, it can be concluded that the desirable management, including the application of no tillage systems, and plant residues can increase the formation and sustainability of aggregates. Management practices (tillage and plant residues) in this rotation had the greatest impact on NSI and WSSI due to their impact on organic matter and less compactness, so that the stability of aggregates was significantly reduced by increasing the tillage intensity, and no tillage and minimum tillage operation practices improved soil structure stability indicators significantly in relation to the conventional tillage. According to the results of this research, it was found that management practices also affect the WSSI of aggregates size distribution, so that the greatest WSSI of aggregates size was obtained in class of > 2 mm (large aggregates) in NT and then MT, due to less plowing.

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