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Changes in soil organic carbon fractions and residence time five years after implementing conventional and conservation tillage systems

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Highlights:

- Conservation tillage practices (CTP’s) increased TOC compared to conventional tillage (CT).
- CTP’s increased OC stabilized by sands and aggregates + particulate OC compared to CT.
- Reduced and minimum tillage reduced dissolved OC compared to CT.
- Stubble cultivator increased the OC stabilized by clay and silt compared to CT.
Changes in soil organic carbon fractions and residence time five years after implementing conventional and conservation tillage systems

Abstract

Tillage not only affects the quantity of soil organic carbon but also its quality. Therefore, an investigation was conducted to see how a five-year (2011-2016) implementation of conventional and conservation tillage practices under dryland vetch - wheat farming system can affect the total organic carbon, TOC, of soil and its fractions as well as its biological indicators including the half-life of organic materials (HL) and the mean residence time (MRT). The applied tillage practices included reduced tillage (RT) with chisel plow, minimum tillage (MT) with stubble cultivator, and no-tillage (NT) with direct seeding as well as conventional tillage (CT) with moldboard plow. The results revealed that all conservation tillage practices (RT, MT, and NT) significantly increased the TOC of examined surface soils (0-25 cm) compared to CT. The labile fraction of soil organic carbon (dissolve organic carbon, DOC) under conservation tillage practices, excluding NT, showed a significant decrease compared to CT. While MT significantly increased the fraction of organic carbon stabilized by clay and silt particles, OC{c+s} compared to CT, NT and RT made no considerable change in OC{c+s} compared to CT. There was also a considerable (but insignificant) increase in the amount of organic carbon stabilized by sand and aggregates plus particulate organic carbon, OC{S+A+POM}, under conservation tillage practices compared to CT. We recorded the greatest (228 ± 21 µg N·g⁻¹·2h⁻¹) and least (98 ± 27 µg N·g⁻¹·2h⁻¹) activity of urease under RT and CT systems, respectively, and the differences were significant. Based on the incubation data, the NT and RT systems significantly resulted in highest HL, (170 ± 9 days) for soil organic materials while CT had the lowest HL, (127 ± 5 days). While RT showed significantly the highest aggregate stability (55 ± 7 %), the CT and MT had the lowest aggregate stability (29 ±
4 %). In general, our results demonstrated the benefits of conservation tillage practices, and more specifically the benefits of RT and NT systems, in improving soil organic carbon, as primary indicator of soil quality, in surface soils under dryland agriculture in terms of quantity and quality of organic carbon.

**Keywords:** Organic carbon fractionation; Chisel plow; Stubble cultivator; Soil respiration
Introduction

Land management, including tillage, can alter the quantity and quality of soil organic carbon (SOC) under agriculture. Many researchers have compared the advantages and disadvantages of conservation and conventional tillage practices. For example, Oorts et al. (2007) used long-term cultivation history to quantify the differences in total carbon and nitrogen stocks after 32 years of no-tillage and conventional tillage systems. Their results showed the soil under a no-tillage system had 10–15% more carbon and nitrogen stocks than soil under conventional tillage. They attributed the physical protection of organic matter under no-tillage as the main reason for the differences in carbon and nitrogen stocks. Moussadek et al. (2014) quantified soil organic carbon stocks in a Vertisol, a Cambisol, and a Luvisol in Central Morocco five years after the application of no-tillage and conventional tillage practices. Their results recorded more soil organic carbon in the Vertisol (10%) and in the Cambisol (8%) under no-tillage, but no difference in the Luvisol. Their results also showed more humic acids and humin under no-tillage, but more fulvic acids under conventional tillage. Laghrour et al. (2016) showed that no-tillage resulted in more soil organic matter than in a conventional tillage system in two Vertisols in Morocco after 11 years. Their results showed no differences between total nitrogen contents bulk densities of no-tillage and conventional tillage systems at the soil surface after 11 years.

Although Boliglowa and Gleń (2003) claim the benefits of conservation tillage are accepted by nearly all people, in many places conventional tillage is still the norm because it may give greater yields, incorporates residues and manures, allows for early earlier sowing after winter, may decrease reliance on herbicides and is suited to poorly drained soils. No-till and conservation (non-inversion) systems that disturb the soil less than conventional systems maintain soil aggregate structures and physically protect the carbon from mineralization (Kane and Solutions, 2015).
However, it seems that the merits of conservation tillage practices in protecting soil organic carbon relies on their application in a continuous mode. Grandy and Robertson (2006) showed that disruption of aggregates by tilling previously untilled soil exposed the carbon molecules to attack by microorganisms and rapidly reversed nearly all the previously recorded gains. However, the is a growing body of literature indicating that occasional or strategic tillage is needed to overcome the limitations of conservation tillage and more specifically no-till (Çelik et al., 2019; Conyers et al., 2019; Dang et al., 2015a; Dang et al., 2015b; Scanlan and Davies, 2019). Because Nunes et al. (2015) and Bogunovic et al. (2018) reported that conservation tillage systems including no-till, NT, and/or reduced tillage, RT, lead to excessive compaction of surface layers due to intense machinery traffic. Zhang et al. (2018) also claim that although conservation tillage practices can decrease soil evaporation and conserve soil water in fields, long-term, mono-conservation tillage practices may end up with low crop yields. Therefore, they suggested employing a rotation of conventional tillage with conservation tillage practices for probable offset of some of the defects induced by the mono- conventional or conservation tillage practices. However, there are still several other researches showing that long-term conservational tillage practices increase soil organic matter (e.g. Pareja-Sánchez et al., 2017).

In contrast to conservation tillage practices that protect soil from disturbance and organic materials from microbial decomposition, crop rotation may compensate for the loss of soil carbon due to tillage by adding more carbon to soil (Kane and Solutions, 2015). However, Martín-Lammerding et al. (2013) showed that intensive tillage practices are the most responsible factor for depleting soil organic matter and loss of aggregation in the Mediterranean region. In contrast, Fernández et al. (2007), Thomas et al. (2007), Hernanz et al. (2009), and Sainju et al. (2009) showed that different tillage practices under semi-arid conditions, similar to our environment, can affect SOC
contents differently confirming that the outcome to be highly site-specific. Thus, those advising farmers need to understand the effects of different tillage practices on soil attributes, especially soil organic carbon content and nature, under different climatic conditions to suggest mechanisms involved in storing organic carbon in soil.

Zimmermann et al. (2007), proposed fractionating soil organic carbon into 1) easily decomposable, 2) stabilized by physicochemical mechanisms and/or 3) biochemically recalcitrant. Partly incorporated plant residues in the soil matrix are easily available for rapid mineralization by microorganisms. Six et al. (2002) and Dungait et al. (2012) showed the importance of physical protection for organic matter and that SOC turnover is mostly governed by accessibility not by recalcitrance. They argued that if decomposers can access SOC, they would degrade it eventually, i.e. within years or decades. Zimmermann et al. (2007) stated that land-use and soil management can affect soil organic carbon both positively and negatively, but the effects are not equal for all fractions and differences between fractions will occur.

Mikanová et al. (2009) investigated the five-year effects of conservation tillage practices (no-tillage, minimum tillage, and no-tillage + mulch) on a range of properties associated with soil carbon. Their results showed a positive influence of conservation tillage practices on reviving the topsoil where the highest activity of urease and microbial biomass carbon content were measured under minimum tillage, the highest dehydrogenase activity as well as the highest counts of Azotobacter spp. and the highest nitrogenase activity were measured under no-tillage + mulch, and the highest activity of invertase and arylsulphatase were measured under all examined conservation tillage practices.

Therefore, this research investigated whether five-year conservation tillage practices changed the total soil carbon in the surface layers of dryland soils in northwest Iran and importantly changed
the distribution of the forms of that carbon. Further, this work examined enzymatic responses to different tillage practices because extracellular enzymes produced by soil microorganisms catalyze chemical reactions involved in SOC decomposition (Cenini et al., 2016). The evaluation of the soil enzymatic responses to different tillage practices may suggest mechanisms for differences in the characterization of the carbon fractions. We also examined the changes in the fractions and half-life of soil organic carbon under different tillage systems. The effects of employed tillage systems on different fractions of the organic carbon and changes in the half-life of soil organic carbon are rarely ever investigated due to difficulties in quantification.

2 Methods and Materials

2.1 Experiment site and soil

This research was carried out in dry-land agricultural research institute (DARI) (latitude 37°16’ N; longitude 46°27’ E; 1730m a.s.l.), 25 km east of Maragheh, East Azerbaijan Province, Iran. The region has a temperate continental climate with warm summers under the Koeppen’s classification system (Hemmat and Eskandari, 2004) with long-term (30-year) average precipitation, temperature and relative humidity of 302 mm, 13°C and 50%, respectively. The soil in study site is classified as fine, mixed, mesic, typic calcixerepts (Hemmat and Eskandari, 2004) based on the USDA soil taxonomy and has a clay loam texture in plow depth (0-25 cm) with 400, 285 and 315 g kg⁻¹ respectively sand, silt, and clay. The experimental site has an average slope of less than 1%.

2.2 Tillage and crop management

We employed a five-year (2011-2016) experiment based on the randomized complete block design (RCBD) having four tillage systems. The tillage systems included conventional tillage (CT) operated by a 3-bottom general purposed moldboard plow equipped with share points, minimum tillage (MT) operated by a stubble cultivator, reduced tillage (RT) operated by a chisel plow
equipped with 6.2 cm points, and no-tillage (NT) operated by a local made drill (ASKE). The applied stubble cultivator consist of a combination of chisel, disc, and roller that simultaneously cuts the soil and smoothly grind after removing the clods with the pressure of the disk blades and leveler’s weight. Kouselou et al. (2018) detailed the equipment, operating speeds, and other features of the tillage practices. The experimental plots had a width of 6 meters and a length of 18 meters.

We rotated the dryland vetch (*Vicia pannonica*) and wheat (*Triticum aestivum*) in experimental site for five years with one crop per year. We replicated the experiments four times to ensure the reduced variability in experimental results.

### 2.3 Soil sampling and laboratory measurements

Composite disturbed soil samples (five subsamples from each plot) from the plow depth (0-25 cm) of all plots were taken at the end of first and fifth years (late September 2012 and 2016 after crop harvest). We used graded regular soil auger to take soil samples from the full 25-cm upper depth of all plots. Soil samples were transferred to the laboratory, air-dried and sieved (< 2 mm). We used soil samples taken in 2012 to determine total organic carbon (TOC) only. While, we used the soil samples taken in 2016 to determine TOC and its fractions as well as soluble polysaccharide content, soil biological responses (urease activity and soil respiration) and wet-aggregate stability.

### 2.4 Soil organic carbon and its fractions

We measured the TOC contents of composite soil samples by wet oxidation technique according to Nelson and Sommers (1982). The procedure of Zimmermann et al. (2007) was used to separate and determine dissolved organic carbon (DOC) and physically or physico-chemically stabilized fractions of soil organic carbon. Thirty grams of soil was suspended in 150 ml water and dispersed the suspension using an ultrasonic probe (Sonopuls, Bandelin) with an output-energy of 22 J ml$^{-1}$.
for 5 minutes. Thereafter, the dispersed suspension was wet-sieved using a 63-µm sieve until the rinsing water runs clear. Organic carbon contents in materials remaining on the sieve consisted the fraction of organic carbon that is stabilized in sand and stable aggregates (S+A) plus non-protected particulate organic matter (POM) which hereafter we will call OC\{S+A+POM\}. We dried the material on the sieve at 40 ºC prior to quantifying OC\{S+A+POM\}. Particles in soil suspension smaller than 63-µm consisted of dissolved organic carbon (DOC) and the fraction of organic carbon stabilized by silt and clay (s+c) portions stabilized, hereafter we call this fraction OC\{s+c\}. Therefore, we separated the DOC and OC\{s+c\} fractions by filtering the suspension < 63-µm using a 0.45 µm nylon mesh. We dried the s+c fraction (i.e. < 63-µm, > 0.45 µm) at 40 ºC prior to determining OC\{s+c\}. We used filtrate < 0.45 µm to determine DOC. Finally, we measured carbon contents in all solid fractions by wet oxidation technique according to Nelson and Sommers (1982); while TOC analyzer (Shimadzu V CPH instrument) determined the carbon contents in liquid samples.

2.5 Soluble polysaccharides

Soil samples were also examined for soluble polysaccharides, SPS, according to the phenol-sulfuric acid method DuBois et al. (1956). Briefly, we mixed 1 g of soil with 10 ml of 0.5 M sulfuric acid and kept it in oven (85 ºC) for 24 h. The mixture was centrifuged at 4838 g (6000 rpm) for 15 min with Eppendorf centrifuge 5810R. Two ml of the separated supernatant was mixed with 0.05 ml of 80% ethanol and 5 ml of 98% sulfuric acid. Finally, total soluble polysaccharide content was determined using a UV-visible spectrophotometer (UV-1800, Shimadzu, Japan) at 490 nm (DuBois et al., 1956). The total SPS content (µg g\(^{-1}\) soil) was calculated from a standard curve developed using known solutions of glucose.
2.6 Urease activity

Urease activity was measured using subsamples from the fresh soil collected as described above and according to the method described by Tabatabai (1994). Briefly, 5 g of soil was placed into a 100 ml Erlenmeyer flask and 2.5 ml of urea solution (79.9 mM) added. The mixture was incubated for 2 hours at 37 °C, then, extracted with 50 ml of 2 M KCl on a circular shaker for 30 min. One ml of supernatant was mixed with 9 ml of deionized water + 5 ml of reagent (100ml NaOH 0.3 M + 100 ml sodium salicylate 1.06 M + 100 ml deionized water) + 2 ml sodium dichloroisocyanurate 39.1 mM. After 30 min, the absorbance was measured using a UV-visible spectrophotometer (UV-1800, Shimadzu, Japan) at 660 nm. A blank solution was also prepared along with soil solutions. The amount of ammonium in the soil suspension and blank solutions were determined (μg ml\(^{-1}\)) from a standard curve. Urease activity is reported as μg NH\(_4^+\) g\(^{-1}\) 2h\(^{-1}\).

2.7 Soil respiration

Soil respiration, \(R_s\), was measured over 38 days in a closed chamber using alkali traps to absorb evolved CO\(_2\) (Bekku et al., 1997). To do this, we put 100 g of dry weight equivalent soil into the microcosms and wetted to a water content of 0.2 g g\(^{-1}\) soil. The samples were incubated at 20 °C with 20 ml of NaOH 0.5N in the chamber. After a known time, the basic solution (NaOH + 2 ml barium chloride + 3 drops of phenolphthalein) was titrated with HCl 0.5 N and the amount of absorbed evolved CO\(_2\) determined. Finally, the data from incubation experiments were fitted to single-pool model (Eq. 1) to predict decomposition rate constant (\(k\)), half-life (HL) (Eq. 2), and mean residence time (MRT) (Eq. 3) of organic carbon for each treatment as recommended by Weihermüller et al. (2018).

\[
    C_t = C_0 \times e^{-kt} \quad (1)
\]

\[
    HL = \frac{\ln(2)}{k} \quad (2)
\]
where $C_t$ is the cumulative CO$_2$ evolved at time $t$ (mg g$^{-1}$), $C_0$ is the total CO$_2$ flux evolved at $t_{end}$ (mg g$^{-1}$), $k$ is decomposition rate constant (day$^{-1}$), HL is half-life (days), and MRT is mean residence time (days).

2.8 Aggregate stability

Wet-aggregate stability (WAS) of 1-2 mm aggregates was determined according to Nimmo and Perkins (2002).

2.9 Statistical Analysis

The measured soil characteristics were tested with analysis of variance (ANOVA) using univariate procedure in SPSS. As TOC was determined at two different times, at the end of first and fifth years, it was subjected to combined analysis of data over years to test the interaction of applied tillage practices and years. Therefore, before pooling data for combined analysis, we checked the homogeneity of error variances between different years by calculating Hartley's $F_{\text{max}}$ statistics and testing it against the Table F value at 5% level of significance. The results showed that the null hypothesis of homogeneity of variance was accepted and, therefore, the data were homogeneous between different years and we could subject them to combined analysis. Finally, when the F-test of ANOVA specified statistical significance at one and 5% probability levels, we classified the means by the least significance difference (LSD) test. Prior to any data analysis, we applied one-sample Kolmogorov-Smirnov test on all data that confirmed the normality of all examined data.

3 Results and Discussion

3.1 Total organic carbon

A combined analysis of total organic carbon (TOC) over time revealed the differences between years ($P \leq 0.05$) and tillage ($P \leq 0.01$) practices (Figure 1). The results revealed that
implementation of different tillage practices on average stored 0.2 mg g\(^{-1}\) organic carbon per year with TOC values of 8.4 vs. 9.2 mg g\(^{-1}\) at the end of first and last years, respectively. The results also show that surface soil under conservation tillage practices (RT, MT, and NT) stored significantly more organic carbon compared to CT with mean TOC value of 9.3 ± 0.74 mg g\(^{-1}\) for conservation tillage practices vs. 7.3 mg g\(^{-1}\) for CT system (Figure 1). Among conservation tillage practices, MT using stubble cultivator and NT systems respectively showed the lowest and highest increase in TOC contents.

Several researchers (e.g. Alvear et al. 2005, Fontana et al. 2015) have reported the positive effects of varied conservation tillage practices on TOC against the conventional tillage system. Faster mineralization of soil organic matter (SOM) in the plowed soil layers associated with exposure from inversion and aggregate breakdown is the most commonly proposed mechanism (Alvear et al., 2005). The less effect of stubble cultivator in increasing TOC content of soils compared to other conservation tillage practices (RT and NT) may be due to greater manipulation of soil by this implement. Although the stubble cultivator requires fewer passes, the extent of the soil disruption remains. Follett (2001) and Paustian et al. (2000), propose that changes in agricultural practices will increase soil organic carbon content if they increase the input of organic residue to soil, decrease the decomposition and oxidation rates of soil organic carbon, or both.

3.2 Soluble polysaccharides and fractions of organic carbon

We take into account the quantification of the soil organic carbon fractions because the detection of the short- and medium-term TOC changes are difficult due to high background C content and its temporal and spatial variability (Bosatta and Ågren, 1994). On the other hand, a decrease in one fraction may offset the changes in TOC by an increase in other fraction. While the fractions and
more specifically the labile C pools usually turn over relatively rapidly (Chen et al., 2009) and therefore, can respond more quickly to employed tillage systems than TOC. The results (Figure 2) showed that different values of SPS and OC{S+A+POM} (insignificant), and OC{c+s} and DOC (significant) fractions were recorded under different tillage practices. Figure 2 illustrates that RT (with 1.17 ± 0.55 mg g⁻¹) and MT (with 0.73 ± 0.12 mg g⁻¹) significantly decreased the DOC content of the soil compared to CT with 2.78 ± 0.12 mg g⁻¹, while NT (with 2.73 ± 0.08) had no effect on DOC content of soil compared to CT practice. DOC is the most labile fraction of soil organic carbon (Chantigny, 2003) and thus is the fraction most likely to respond quickly to changes by tillage practice. The greater DOC concentrations found here under CT system result from faster residue decomposition under this system. However, there is no clear explanation for more DOC under NT. Leenheer and Croué (2003) suggest the main composition of DOC consists of the relatively high molecular weight materials including humic, fulvic acids, and the lower molecular weight materials including proteins, organic acids, carbohydrates and other compounds. For the residues from the same species of crops grown in this experiment, Baumann et al. (2009) showed that vetch residues consisted of less carbohydrates (60 vs. 74 %) and lignin (14 vs. 22 %), but greater lipid (7 vs. 1 %) and protein (19 vs. 2 %) than wheat residues. Since carbohydrates are an easily decomposable part of the organic residues it seems that, the lower contents of DOC under conservation tillage practices are due to the slower decomposition rate of organic materials. Our results revealed that OC{A+S+POM} content of soil under conservation tillage practices (RT, MT, and NT) with mean value of 2.08 ± 0.23 mg g⁻¹ appears to be, but was not significantly greater than that under CT system with OC{A+S+POM} value of 1.6 ± 0.17 mg g⁻¹ (Figure 2). Greater OC{A+S+POM} content under conservation tillage practices has been attributed to the increased stability of aggregates, with the more stable aggregates protecting the organic materials from
exposure and decomposition. Several researches, e.g. Beare et al. (1994); Peixoto et al. (2006); Jabro et al. (2015), have shown that aggregate stability can be decreased by extensive tillage operations. Figure 3 confirms increased wet-aggregate stability, WAS, under conservation tillage practices, more specifically under RT and NT systems with mean value of WAS of 45 ± 14 %, compared to CT with WAS value of 32 ± 1 %. However, WAS under MT (27 ± 7 %) showed a considerable decrease compared to CT with WAS equal to 32 ± 1 %. Despite the significant differences of WAS among tillage practices, mean weight dimeter (MWD) indicator was not different based on the size of the stable aggregates (Figure 3) and appears to be a less sensitive indicator. All examined plots comprised, in overall, 23 ± 9 % sand fractions (> 0.25 mm) within stable aggregates.

The SPS content of examined soil showed no significant increase under conservation tillage practices (RT, MT, and NT) with mean value of 100±6.5 mg g⁻¹ compared to 90±11.4 mg g⁻¹ under CT system. Thus, it seems to be unlikely for cellulose polysaccharide to persist intact in surface soil horizons unless other factors protected it from microbial decomposition.

Unlike the DOC and OC{A+S+POM}results seen in Figure 2, different conservation tillage practices affected the OC{c+s} fraction differently where OC{c+s} content under MT increased significantly while it was not changed under NT compared to CT (Figure 2). This suggests that the stubble cultivator extensively breaks down the soil aggregates and thus provides more free sites of silt and clay particles to protect organic carbon fractions.

While the number of reports connect conservation tillage practices with organic matter fractions under similar rotations, climates and soils is very limited they tend to show positive effects of conservation tillage practices on different fractions of soil organic carbon. For example, Carbonell-Bojollo et al. (2015) investigated the 3-year effects of no-till and conventional tillage systems
paired with peas-wheat-sunflower crop rotation on soil organic carbon fractions. Their results revealed that no-till system improved the levels of the different fractions of soil organic carbon in the surface soil compared to conventional tillage.

<<Figure 2 about here>>

<<Figure 3 about here>>

3.3 Biological responses

We evaluated the effects of applied tillage practices on urease activity and soil respiration after harvest of the fifth crop. Figure 4 shows that conservation tillage practices (with average urease activity of $173 \pm 15 \mu g \text{NH}_4^+ \cdot g^{-1} \cdot 2h^{-1}$) significantly increased the urease activity of soil compared to CT ($98 \pm 27 \mu g \text{NH}_4^+ \cdot g^{-1} \cdot 2h^{-1}$). Among the conservation tillage practices, the highest activity of urease ($228 \pm 21 \mu g \text{NH}_4^+ \cdot g^{-1} \cdot 2h^{-1}$) was recorded in RT, while the lowest activity of urease ($125 \pm 3 \mu g \text{NH}_4^+ \cdot g^{-1} \cdot 2h^{-1}$) was recorded in NT. It seems that the decrease in soil disturbance and the increase in soil organic matter (Figure 1) most probably cause the difference in urease activity. Alvear et al. (2005) and Mikanová et al. (2009) reported the incremental effect of conservation tillage systems compared to conventional tillage on activities of soil enzymes. Their results revealed greater activity of urease under minimum tillage system compared to the conventional tillage and no-tillage systems. Dick (1994) suggested that intensive soil plowing tends to decrease soil enzymatic activity. The lower urease activity under no-till, despite the less manipulation of the soil, compared to reduced and minimum tillage systems needs to be investigated more in detail. It may be linked to our unquantified observation of less water in the soil under no-till system compared to RT and MT. Because Alvear et al. (2005) showed that urease activity in winter was greater than in summer and they concluded that the ureolytic bacteria are dependent upon soil water content. Meydani et al. (2014) working in the same region as our research showed more soil...
water in soil managed with chisel plowing compared to other tillage practices including conventional and no-tillage systems.

Figure 5 reveals that conservation tillage practices significantly decreased decomposition rate, $k$, and increased half-life (HL) and mean residence (MRT) times of soil organic carbon compared to CT. Conservation tillage systems with mean $k$ value of $1.57 \pm 0.08$ day$^{-1}$ and CT with $k$ value of $2.0 \pm 0.08$ day$^{-1}$ showed the slowest and fastest decomposition rates, respectively. RT system with HL time of $176 \pm 6$ days and MRT time of $254 \pm 8$ days showed the most protective practice for soil organic materials. The $k$, HL and MRT values under MT system with stubble cultivator (with $k = 1.68 \pm 0.04$ day$^{-1}$, HL = $151 \pm 3$ days, and MRT = $218 \pm 5$ days) were close to those in CT (Figure 5). It seems that protection of soil organic materials in more stable aggregates is the main reason for lower decomposition rate and higher residence time of organic materials in RT and NT systems compared to CT and MT. The protected organic matter is likely to provide the positive effect of greater wet-aggregate stability of soil in RT and NT than under CT and MT.

<<Figure 4 about here>>

<<Figure 5 about here>>

### 4 Conclusion

This research evaluated the mid-term effects (over five seasonal years) of different tillage practices on soil organic carbon, its different fractions as well as soil urease activity and soil respiration as indicators of biological responses of soil. We also examined the half-life of soil organic carbon under different tillage systems as this is rarely studied. Therefore, we compared three different conservation tillage practices (RT, MT, and NT) to conventional tillage under vetch – wheat crop rotation in a competitive way. The following conclusions can be drawn from our results:
• Conservation tillage practices increased the quantity of soil organic carbon compared with conventional tillage.

• All conservation tillage systems insignificantly increased the fraction stabilized by sand particles and aggregates plus particulate organic carbon, OC{S+A+POM}, compared to conventional tillage.

• No-tillage had no effect on the labile fraction of soil organic carbon (DOC) compared to conventional tillage while the applied reduced tillage and minimum tillage reduced the DOC content.

• Stubble cultivator increased the organic carbon stabilized by clay and silt fractions, OC{c+s}, compared to both conventional and no-tillage tillage systems.

• All conservation tillage systems increased the activity of the urease enzyme in soil compared to conventional tillage.

• Reduced tillage and no-tillage systems with an average organic matter half-life of 170 ± 9 days and mean residence of 245 ± 13 days were the most protective practices for soil organic materials compared to conventional tillage and stubble cultivator.

As a final conclusion, we have demonstrated that after 5 years of a vetch-wheat rotation in dryland conditions reduced and no-tillage systems increased soil organic carbon by increasing the mean residence time and decreasing turn-over.

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6 References


Oorts, K., Bossuyt, H., Labreuche, J., Merckx, R., Nicolardot, B., 2007. Carbon and nitrogen stocks in relation to organic matter fractions, aggregation and pore size distribution in no-


Figures captions:

Figure 1- Comparisons of mean values of total organic carbon (TOC) of soil over first (Year 1) and last (Year 5) years of the experiment under different tillage systems. CT: conventional tillage with moldboard plowing, MT: minimum tillage with stubble cultivator, NT: no-tillage with direct seeding, and RT: reduced tillage with chisel. Error bars show the standard error of the mean values.

Figure 2- Comparisons of mean values of the stabilized organic carbon (OC) in silt and clay fractions (OC_{s+c}), the stabilized OC in sand and stable aggregates plus non-protected particulate organic matter (OC_{S+A+POM}), dissolved organic carbon (DOC), and soluble polysaccharides (SPS) under different tillage systems. CT: conventional tillage with moldboard plowing, MT: minimum tillage with stubble cultivator, NT: no-tillage with direct seeding, and RT: reduced tillage with chisel. Error bars show the standard error of the mean values.

Figure 3- Comparisons of mean values of soil aggregate stability (WAS) and mean weight diameter (MWD) among different tillage systems. CT: conventional tillage with moldboard plowing, MT: minimum tillage with stubble cultivator, NT: no-tillage with direct seeding, and RT: reduced tillage with chisel. Error bars show the standard error of the mean values.

Figure 4- Comparisons of mean values of soil urease activity among different tillage systems. CT: conventional tillage with moldboard plowing, MT: minimum tillage with stubble cultivator, NT: no-tillage with direct seeding, and RT: reduced tillage with chisel. Error bars show the standard error of the mean values.

Figure 5- Comparisons of mean values of organic materials decomposition rates (k), half-life (HL), and mean residence time (MRT) under different tillage systems. CT: conventional tillage with moldboard plowing, MT: minimum tillage with stubble cultivator, NT: no-tillage with direct seeding, and RT: reduced tillage with chisel. Error bars show the standard error of the mean values.
Figure 1
Figure 2
Figure 3

Figure 4
Figure 5