# PATHWAYS AND RATES OF SOIL ORGANIC MATTER LOSSES IN ARABLE TILLED LANDS OF TWO EXTREME CLIMATES

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## EXTENDED ABSTRACT

Conversion of native to agricultural lands results in losses of soil organic matter (SOM). The magnitude of the losses is a function of climate, soil-type stabilization mechanisms, and agricultural management. A compilation of literature data presented in this paper suggests that the relative rate of SOM loss, after the conversion of native grassland to arable tilled land decreases in time following a logarithmic pattern. Loss of SOM and degradation of its quality makes soils more susceptible to erosion and desertification with global consequences for food security, climate change, water quality, and agricultural economy. The study of SOM stocks, composition, and stabilization mechanisms for a wide range of climate, land use, and soil types is important to improve SOM modelling and soil restoration techniques. In this work, we report the quantitative and qualitative changes in soil aggregates and particulate and mineral-related OM within the aggregates, for croplands and set-aside control-fields in two extreme climate environments (Humid Continental, Mediterranean).

Large and medium aggregates were significantly lost from Iowa cropland (IA) compared to the set-aside field. Particulate organic matter (POM) losses were attributed to the destruction of macroaggregates (> 250 μm) resulting in the total soil OC loss. The mineral organic matter (MOM) fractions were higher in cropland compared to the set-aside field. This increase could be explained by the MOM derived from the destructed (oxidized) macroaggregates. On the other hand, POM and MOM losses attributed to the destruction of macroaggregates in Greek soils (GR) can explain only 38% and 27% of the total soil OC loss, respectively. The remaining loss was due to the MOM lost from the finer aggregates (<250 μm). Moreover, lower decomposition rates were observed in GR soils compared to IA soils. This could be presumably attributed to dry climatic conditions in conjunction with loamy soil texture, as well as a lack of regular plowing, while the quantity of earthworms may also play a significant role. The two different patterns of OM losses observed between IA and GR indicated that in cropland GR the rate of OM erosion is higher than the rate of stabilization of new OM in fines, while in IA the two rates are at least equal. These two patterns have also been observed at other sites, but no climatic or textural trend was observed in the available literature data. However, we observed sites which present patterns similar to IA including a markedly reduction of large and medium macroaggregates, while those soils similar to GR exhibited less reduction. Under certain conditions (i.e macroaggregate turnover rate, decomposition rate) the re-distribution of POM due to tillage might result in a higher rate of new OM stabilization with organo-mineral interactions, which compensates for the higher rate of OM erosion usually observed in croplands.

**KEYWORDS**: soil organic carbon and nitrogen loss, croplands, aggregate fractionation, particulate and mineral organic matter, Mediterranean, humid continental climate.

## 1. INTRODUCTION

Conversion of native lands to agricultural lands results in losses of soil organic matter (SOM). The magnitude of the losses is a function of climate, soil type-stabilization mechanisms, and agricultural managements (Muller et al., in press). A compilation of literature data presented in this paper suggests that the relative rate of SOM loss, after the conversion of native grassland to arable tilled land decreases in time following a logarithmic pattern. The first year loss is one order of magnitude greater than slope losses observed after many years of the conversion. However the few data did not allowed any climatic pattern to be drawn. Loss of SOM and degradation of its quality makes soils more susceptible to erosion and desertification with global consequences for food security, climate change, water quality, and agricultural economy (Lal, 2004). The study of SOM stocks, composition, and stabilization mechanisms for a wide range of climate, land use, and soil types is important to improve SOM modelling and soil restoration techniques (Rees et al., 2005).

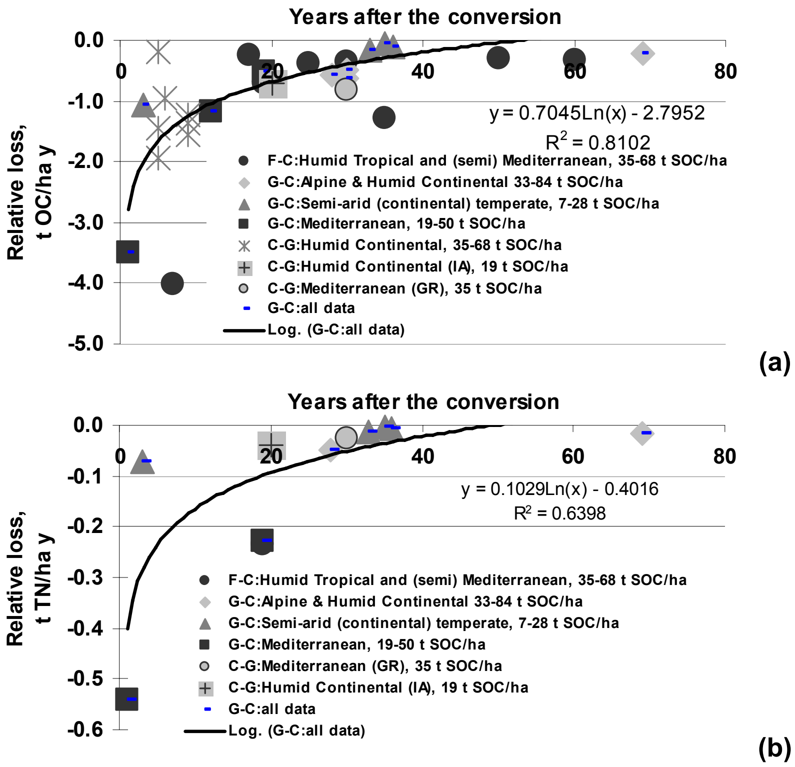



**Figure 1**: Relative slope loss of soil a) OC and b) TN, after the conversion of native land to arable land, under conventional tillage and vise versa (normalized to 10 cm soil depth).

Responsible for the short term loss of SOM is the removal of the dense root system from the topsoil which results in less litter input. Every tillage event induces an ‘instantaneous type’ loss of SOM. Just one plowing event after a period of conservation tillage has been found to evenly distribute SOM throughout the ploughed layer and induce a partial loss of SOM within a few weeks after the event (Koch and Stockfisch, 2006). During tillage macroaggregates are rapidly destroyed and release inter and intra particulate organic matter (POM) and microbial binding agents. The released OM can be readily oxidized and mineralized or solubilized, affecting the quantity and quality of dissolved organic matter (Grandy and Neff, 2008). SOM loss from the more stabilized finer soil fractions is induced by the higher macroaggregate turnover observed in croplands; according to the hierarchical aggregate formation conceptual (Six et al., 2000), incoming OM is re-exposed more quickly than it is occluded (Plante and McGill, 2002) and therefore more OM is mineralized and less stabilized in microaggregates and silt-clay sized soil fraction.

However, the finer fractions are also texturally enriched by the destruction of macroaggregates.

In this work we aimed at studying the quantitative and qualitative changes in soil aggregates and particulate and mineral-related OM within the aggregates, for croplands and set-asidecontrol-fields in two extreme climate environments (Humid Continental, Mediterranean).

## 2. METHODOLOGY

**Soil Sampling:** Bulk topsoil samples (0-10 cm) were taken from a cropland and an adjacent set aside field with native vegetation, from two different climate sites. The first site was located in Iowa City, IA, USA and was indicative of humid continental climate; the second site was in the northern part of Chania Perfecture, Crete, Greece, where typical Mediterranean climate dominates. Both sites were located near the floodplain (Iowa River and Koiliaris River) and therefore soils were recent depositions. Iowan soils are very deep, formed in colluvium alluvial fans, and characterized as colo-ely (Udolls Mollisols). The arable field was conventionally tilled and used for the production of corn and soybeans. Prior to being set aside, 20 years ago, the uncultivated filed received the same management. Cretan alluvial deposits (Quartenary formations) are shallower than Iowan and characterized as calcaric Regosols (Entisols). The arable field was used for the production of green vegetables and was sporadically tilled. The set aside field was 30 years old.

***Aggregate fractionation procedure:*** Bulk soil was separated into five water stable aggregate fractions: i) large macroaggregates>2000 μm, ii) 1000 μm<medium macroaggregates<2000 μm, iii) 250 μm<small macroaggregates<1000 μm, iv) 53 μm<microaggregates<250 μm, and v) silt-clay sized microaggregates and minerals<53 μm. Aggregate fractions were determined on triplicates, where air-dried soil (40 g) was quickly submerged in deionized water on top of the 2000 μm sieve (for 5 min), which was then moved up and down over 2 min with a stroke length of 3 cm for 50 strokes. Sieving was repeated on the 1000 μm (40 strokes), 250-μm (30 strokes) and 53-μm (10 strokes) sieves using the soil plus water that passed through the next larger sieve (Elliott, 1986). Aggregates remaining on each sieve were oven-dried at (60°C), weighed and stored in glass jars at room temperature. Sand content was determined on an aggregate subsample after dispersing soil in sodium hexametaphosphate (0.5%) for 18 h on a rotary shaker at 190 rpm.

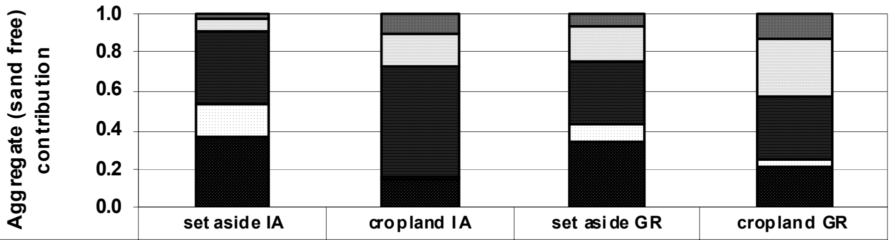
***Microaggregate isolation procedure:*** A subsample (10 g) of small macroaggregates (250 to 1000 μm) and of composite macroaggregates (>250 μm) was further separated into the following fractions by particle size fractionation based on Lichter et al., (2008): i) coarse particulate organic matter and sand (cPOM: >250 μm), ii) microaggregates (mM: 53-250 μm), and iii) easily dispersed silt-clay fractions (sc-M <53 μm). The three fractions were oven-dried at (60°C), weighed and stored in glass jars at room temperature. The microaggregates (mM) as well as the free microaggregates (53-250 μm) from the aggregate fractionation were further similarly separated to fine particulate organic matter and sand (fPOM: 53-250 μm) and silt-clay fraction of the microaggregate (sc-mM <53 μm).

***Chemical analysis:*** Bulk soil, aggregates and fractions from Microaggregate isolation procedure were measured for their content in OC by a TOC analyzer-solid sample module SSM-5000 (total and inorganic C were measured) and Total Kjeldahl N (TKN) by the Kjeldahl digestion technique with a Hach digestahl digestion apparatus (Nessler method, 8075). The OC and TKN content of the sc-mM fraction was not measured but estimated as the difference between the rest fractions and the aggregate content.

## 3. RESULTS AND DISCUSSION

**Bulk soil:** Set aside fields showed an increase of soil organic carbon and total Kheldahl nitrogen compared to the continuously cultivated adjacent fields both in IA and GR. The OC density (t/ha) was increased by 43 (IA) and 40 (GR) % after 20 and 30 years of set aside practice, respectively. Similarly, increase was observed for TKN, 33 (IA) and 24 (GR) %. The increase of OM was accompanied by 19 and 6 % decrease of soil bulk density for IA and GR, respectively. The C-to-N ratio was lower in croplands (11.7-IA and 13.0-GR) compared to set aside fields (13.8-IA and 16.5-GR), indicating less stabilized OM in croplands. The OC density decreased at a rate 0.721 and 0.809 t OC /ha y in IA and GR, respectively, while the TKN density decreased at a rate 0.040 and 0.027 t TKN/ha y in IA and GR, respectively-compared to the control set aside field.

**Water stable aggregates**: The large and medium macroaggregates (>1000 μm) contributed to the total water stable aggregates 50.3 (IA) and 37.7 (GR) % in set aside fields while in the croplands for 8.6 (IA) and 19.4 (GR) % (Figure 2). The weight of 1000-2000 μm aggregate fraction of the cropland IA was negligible. The small macroaggregates (250-1000 μm) were more or less the same for both IA (31.4-30.1%) and GR (27.9-26.4 %) in set aside fields and croplands. It is worth noting that, not corrected for sand, this aggregate fraction would increase from 35.9 (set aside field) to 57.3 g/100 g soil in cropland IA, while it would remain the same for the two soils in GR. On the other hand, free microaggregates (53-250 μm) and silt-clay sized fraction (<53 μm) were texturally enriched in croplands: 1.6-2.4 (IA) and 1.5-1.8 (GR) times higher compared to set aside fields. Water stable aggregates were 89.8 (IA) and 87.2 (GR) g/100 g soil in set aside fields, while in croplands decreased to 53.4 (IA) and 59.6 (GR) g/100 g soil. The mean weight diameter (MWD) of sand-free aggregates was calculated as an index of aggregate stability and found to be 33 and 26 % lower in croplands compared to set aside fields (0.82 and 0.71 mm), for IA and GR, respectively. The sand content of the destroyed large macroaggregates (set aside GR) served as a 'conservative' indicator explained the total sand enrichment of the 53-250 μm aggregate fraction in cropland GR. Although the cropland IA is sandier than set aside IA, at least 20% of the sand released from large macroaggregates (set aside IA) can be found in small macroaggregates of the cropland.




| | set aside IA | cropland IA | set aside GR | cropland GR |
|---|---|---|---|---|
| < 53 μm | 2.22 | 5.29 | 5.65 | 10.07 |
| 53-250 μm | 5.87 | 9.37 | 15.90 | 23.67 |
| 250-1000 μm | 35.34 | 30.15 | 27.92 | 26.44 |
| 1000-2000 μm | 15.73 | 0.41 | 8.09 | 2.85 |
| > 2000 μm | 34.58 | 8.16 | 29.58 | 16.55 |

**Figure 2**: Aggregate fractionation of IA and GR soils (g aggregate/soil, sand corrected).

**OC and TKN concentration of aggregates**: The OC and TKN concentration was similar in macroaggregates, highest in 53-250 μm aggregates and lowest in <53 μm, in both set aside soils. Nevertheless, the OC and TKN concentrations were higher in GR compared to IA set aside soil, reflecting the higher soil OM content of this soil (Figure 3). Tillage in Iowa cropland resulted in the decrease of the OC and TKN concentration of the >2000 μm aggregates. Much more than textural explained loss (meaning that OM loss was greater than the aggregate weight loss) was observed in > 2000 and 250-1000 μm aggregates in croplands compared to set asides, in both IA and GR and in finer aggregates (<250 µm) of GR (Figure 3). On the other hand, the finer aggregates of IA exhibited more than textural explained enrichment in OM content. Totally, the textural explained loss/gain registered at the 75 and 92 % of the total loss of OC and TKN in IA, while in GR only 27 and 11 % respectively. Worth noting is the reduction of C/N ratio of all aggregates in GR, which indicates a more decomposed OM. Decline in C/N ratio was also observed in the 250-1000 µm aggregate fraction of cropland IA. The large macroaggregates contributed to total soil OC and TKN 54-56 (IA) and 71-74 (GR) % in set aside fields, while in the croplands this contribution decreased to 10-9 (IA) and 39-42 (GR) % (Figure 4).

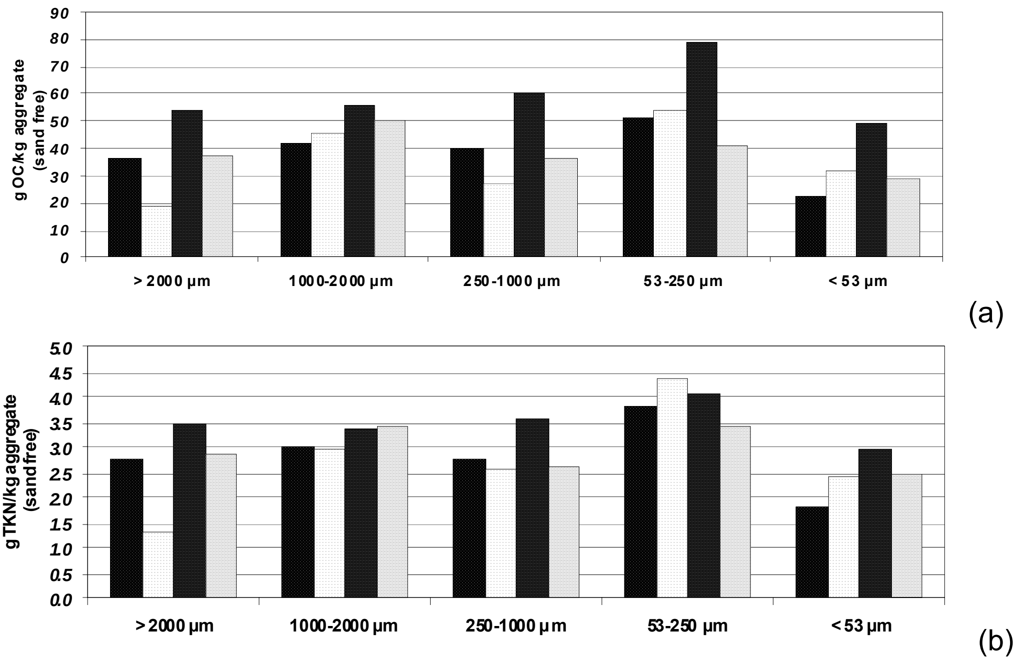



**Figure 3**: a) OC and b) TKN concentration of soil aggregate fractions.

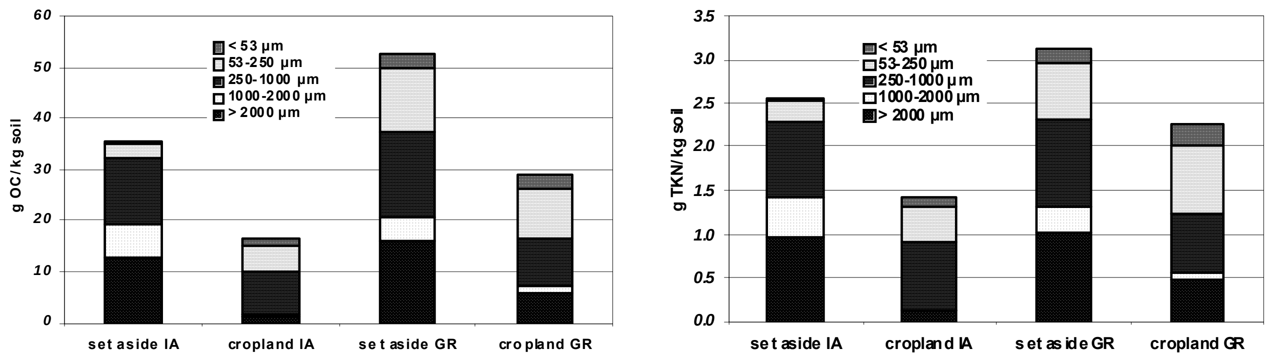



**Figure 4**: Soil a) OC and b) TKN content and distribution among aggregates fractions.

**Microaggregate Isolation:** The ratio of the weight of sand corrected microaggregates (contained in macroaggregates-mM) to the weight of sand corrected macroaggregates have been found to be 2 times lower under conventional tillage compared to no tillage practice (Six et al., 2000). We noticed a similar but proportionally lower decrease of the ratio in croplands (Table 1). However, it should be mentioned that cropland IA is sandier than set aside IA.

**Table 1**. Ratio of microaggregates(mM)/macroaggregates weight and ratio of fPOM/cPOM OC density-sand corrected (in bold).

| | Set Aside | Cropland | Set Aside | Cropland |
|---|---|---|---|---|
| | *Composite macroagrregates* | | *250-1000 μm macroaggregates* | |
| IA | 0.39 | 0.31 | 0.28 | 0.22 |
| GR | 0.42 | 0.46 | 0.45 | 0.42 |
| IA | **10.0** | **7.9** | **23.4** | **8.1** |
| GR | **13.2** | **8.5** | **11.0** | **7.5** |

***cPOM***: OC and TKN concentration as well as C-to-N ratio of cPOM in set aside IA, was found to be lower in 250-1000 μm compared to composite macroaggregates, indicating more decomposed and older POM in smaller macroaggregates (Figure 5). On the contrary, in set aside GR these concentrations were similar indicating lower decomposition rate compared to IA, due to dry climate. Croplands exhibited 1.5 (GR) and 4.5 (IA) times lower concentrations compared to set aside fields. More than texturally explained loss and lower C-to-N ratio as compared to the set aside field observed in cropland IA could be attributed to enhanced decomposition as a result of tillage effect and sandier texture.

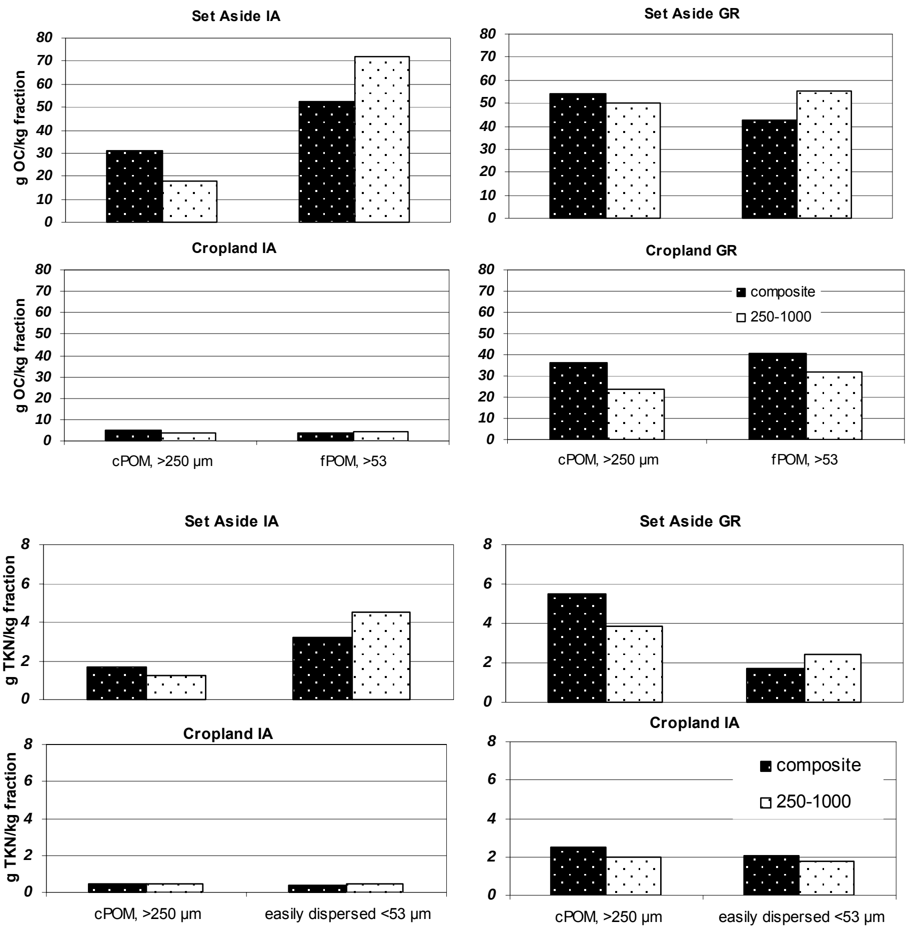
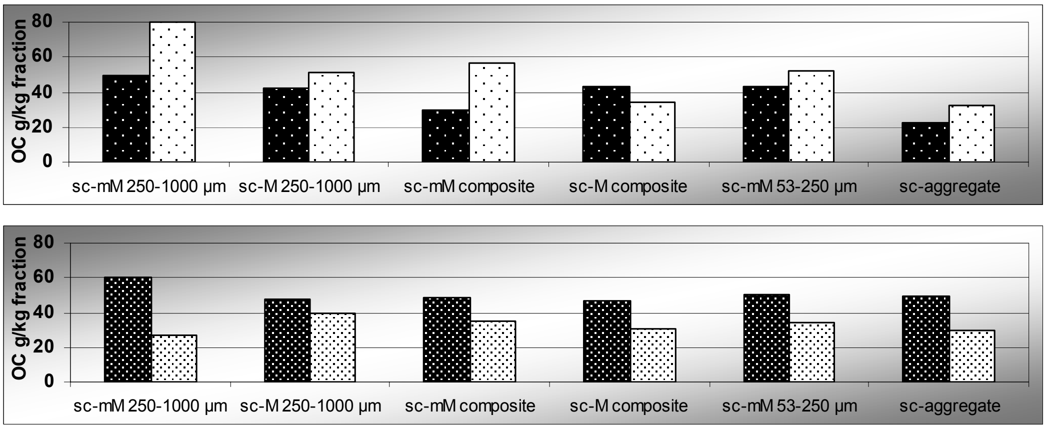



**Figure 5**: a) OC and b) TKN concentration-not sand corrected-of POM fractions isolated by the microaggregate isolation procedure.

***fPOM***: OC and TKN concentration of fPOM isolated from microaggregates in set aside fields was higher in 250-1000 μm macroaggregates compared to composite macroaggregates (Figure 5). The C-to-N ratios were similar. Conversely, croplands exhibited lower concentrations (sand corrected) of fPOM in 250-1000 μm macroaggregates, but C-to-N ratio was significantly lower only in IA. This pattern suggests destruction of the ability of the soil to stabilize new POM in microaggregates in croplands as compared to set aside fields. Similarly with cPOM, OC and TKN concentration of fPOM was significantly higher in set aside fields as compared to croplands.

***Mineral-related organic matter fractions (MOM) fractions***: OC and TKN concentrations of easily dispersed mineral sized fraction (sc-M) microaggregate related mineral fraction (sc-mM) and free silt-clay sized aggregates in set aside soil GR were not statistically different. Exemption was the sc-mM fraction of the 250-1000 μm aggregates. In set aside IA, however, the OC and TKN concentration of free silt-clay sized aggregates was significantly lower than the rest, indicating that more exposed OM is more prone to mineralization in IA due to dominated humid climatic conditions. Cropland GR presented lower OC and TKN concentrations in all mineral fractions compared to set aside GR. On the contrary, cropland IA exhibited higher concentration in all mineral fractions compared to set aside IA.



(a)
(b)

**Figure 6**: OC concentration of soil mineral fractions in a) IA and b) GR set aside field and cropland.

## 4. CONCLUSIONS

Large and medium aggregates were significantly lost from Iowa cropland (IA) compared to the set-aside field. The POM loss attributed to the destruction of these aggregates can explain 74 % of total soil OC loss (cPOM alone 58 %). The POM loss in 250-1000 μm macroaggregates can explain the rest 24 % of total soil OC loss. The concentration of mineral organic matter (MOM) fractions was increased in cropland as compared to set aside field IA. The increase of the contribution of <250 μm aggregates in cropland IA was about 3.3 g/kg soil and could be entirely attributed to MOM increase, while the decrease of the MOM in >1000 μm macroaggregates was about 3.2 g/kg soil, explaining the enrichment of the finer fractions. Large and medium aggregates in GR were not diminished as much as in IA. POM loss attributed to the destruction of these aggregates can explain the 28 % of total soil OC loss (cPOM alone the 8 %). Another 10 % was attributed to the POM loss from small macroaggregates. Moreover, loss was observed in MOM fraction (7 and 21 % of total soil loss in small and large-medium aggregates). POM and MOM loss from macroaggregates could explain the 65 % of total soil OC loss. The remaining loss was mainly due to the MOM lost from the finer aggregates (<250 μm). Moreover, lower decomposition rates were observed in GR soils compared to IA soils. This could be presumably attributed to dry climatic conditions in conjunction with loamy soil texture, as well as a lack of regular plowing, while the quantity of earthworms may also play a significant role. The ratio of the fPOM-OC to cPOM-OC has been suggested (Six et al., 2000) as an indication of turnover rate (the higher the ratio, the lower the turnover rate). Indeed, it was found to be lower in croplands compared to set aside fields, indicating that tillage results in higher turnover macroaggregate rates. We suggest that this ratio is also a function of decomposition rate, so it is fundamentally expected to be higher in IA where the decomposition rate is higher. This was indeed the case in 250-1000 macroaggregates. However the ratio in composite macroaggregates was higher in GR. This could be interpreted as indication of lower macroaggregate turnover rate in GR. The two different patterns of OM losses observed between IA and GR indicated that in cropland GR the rate of OM erosion is higher than the rate of stabilization of new OM in fines, while in IA the two rates are at least equal. These two patterns have also been observed at other sites, but no climatic or textural trend was observed in the available literature data. However, we observed sites (Emadi et al., 2009) which present patterns similar to IA including a markedly reduction of large and medium macroaggregates-80 to 91 % less large and medium macroaggregate OC in total soil OC, while those soils (Gupta and Germida, 1988; Bongiovanni et al., 2007) similar to GR exhibited similarly to GR less macroaggregate reduction -45 to 65 % less large and medium macroaggregate OC in total soil OC. Under certain conditions (i.e macroaggregate turnover rate, decomposition rate) the re-distribution of POM due to tillage might result in a higher rate of new OM stabilization with organo-mineral interactions, which compensates for the higher rate of OM erosion usually observed in croplands.

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