Impact of Nitrogen Fertilization on Soil Organic Carbon Decomposition

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ABSTRACT

A field study was conducted at The Experimental Farm, Fac. of Agric., Al-Azahar University, Assuit, located 375 km south of Cairo, Egypt (27° 12- 16.67= N latitude and 31° 09- 36.86= E longitude) through wheat growing season 2015. The aim of current study is to asses the effect of nitrogen fertilizer types (urea and ureaform) at different levels on soil organic carbon decomposition.

Soil organic carbon decomposition percentage (SOCD) is at a minimum amount in the 2nd week and at a maximum amount in the 7th week at the recommended urea level - 15% (R-15%). The biweekly SOCD % varied from 0.82 and 9.55 % at 70 kg N/fed level (R-30%). SOCD% ranged between 0.16- 12.73, 5.14- 10.61 and 0.41-8.78% for ureaform level at (R-15%) and (R-30%) less than the recommended one (R), respectively. The amount of soil CO_2 flux from recommended ureaform level treatment was the highest one during the entire growing season. Overall, SOCD% followed the order of R > R-15% > R-30%. The highest values of SOCD % were 8.4 and 8.2 at 2.4 Q_{10} value with urea and at 2.7 Q_{10} value with ureaform, respectively. The lowest values of SOCD % were 2.3 and 4.4 at 2.2 Q_{10} value with urea or ureaform, respectively. Soil C: N raties under all treatments were higher than that of initial state except that under R-30% of urea. The soil C: N ratio was higher at R-15% of urea than that when soil treated by ureaform. The opposite trend is true at R-30%.

Key words: Nitrogen fertilizer, Soil carbon decomposition, C: N ratio, Temperature sensitivity, Wheat crop.

INTRODUCTION

Nitrogen (N) is a substantial element for all life on Earth. Litter decomposition is essential for the cycling of carbon (C) and nutrients in terrestrial ecosystems. By decomposition, C and nutrients that immobilize in the litter are released and once again becomes available to plants. Overall, it is controlled by the interactions between the decomposer organisms, the litter properties, and the abiotic environment. However, the interactions are not yet fully understood. One interaction we do not fully understand is the one between C and nitrogen (Russell et al., 2006). Generally, the data indicated the increases in T-N, Av-P and Av-K as indicators of improvement in the fertility in the treated soil. The high increase in nutrients content in the soil treated with T4 (40% M.F + 60% O.M) at the end of study may be attributed to its decomposition and producing organic acids (Abedel-Sattar et al 2011). Besides its scientific interest, understanding how N affects organic matter (OM) decomposition has become important in a global change perspective. During the last century, the N deposition has increased, mainly as a result of increased production, use of fertilizers, increased combustion of fossil fuels, and it is predicted to continue to increase (Galloway et al., 2004 & 2008).

Nitrogen fertilization studies showed that adding N can increase, decrease, or have no effect on the decomposition rate (OM). A decreased or unchanged decomposition rate, together with an increased plant biomass production, may decrease the concentration of atmospheric CO_2. However, if both the plant biomass production and the decomposition rate increase, the consequence for the atmospheric CO_2 concentration is unclear. Given the importance of litter decomposition for element cycling in ecosystems, and the uncertainties regarding responses and feedbacks to global change, an increased understanding of the interaction between C and N during decomposition is desirable (Hobbie, 2005 and Knorr et al., 2005). It can be concluded that combined use of organic manure such as farm yard manure (FYM) with mineral nitrogen fertilizer would maintain high microbial biomass and respiration in calcareous soil (Elsokkary etal.2011).

Carbon decomposition from organic residues is controlled by many factors soil environmental conditions (temperature, moisture, aeration, soil pH, nutrient availability, etc), substrate quality (chemical composition) and quantity, soil residue pretreatment, application methods and their potential interactions. There was a significant higher effect of inorganic N fertilizer on organic matter content in combination with manure than that when it applied alone. Lacking, however, is an integrated assessment of the effects of N fertilization on the processes that influence the soil C balance. The balance of organic carbon (OC) in the soil is determined by rates of (OC) inputs from net primary production (NPP) of the crops plus any manure additions, and rates of (OC) decay (Russell et al. 2006; Khan et al. 2007 and Liu et al., 2010).

The input and decay rates of (OC) can be influenced by environmental factors, including temperature, precipitation, and soil type, and by management factors such as tillage and fertilization. Fertilizer additions

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Received November 18, 2015, Accepted December 20, 2015

could influence NPP, thus the quantity of (OC) inputs. Fertilization could alter the partitioning of NPP among plant components above and below ground, and thereby influence the (OC) decay rates if decay rates differ with respect to location of decomposition. Finally, N fertilization could alter the crop-tissue chemistry, which would influence its decomposition rate. Long-term studies indicated that initial N concentration drives litter decay rates (Johnson et al.، 2005 and Parton et al., 2007). The world's soils are estimated to contain 3000 Gt carbon, which is three times the estimated amount of atmospheric CO_2-C. Thus, even small changes in the soil carbon pool may severely affect the atmospheric CO_2-concentration, thereby further affecting the global air temperature. The decomposition of organic material has been shown to be more sensitive to temperature than net primary production (Tarnocai et al., 2009 and Conant et al., 2011).

Decomposition is the process by which organic matter in (or on top of) the soil is converted into progressively smaller pieces and eventually inorganic compounds. Bacterial and fungal decomposers are responsible for more than 95% of the biotic part of OM decomposition. Decomposers use organic matter as a source of metabolic (e.g. carbohydrate) energy and as a source of nutrients. The form of N added varies across studies, yet we know little about how different N forms may impact microbial processes. N additions to soil can affect microbial activity, yet it is not clear if these impacts are a direct function of the increase in N availability or a result of indirect effects of the fertilizer inputs on other soil chemical characteristics. The soil C: N ratio is a soil fertility indicator due to the close relationship between soil organic carbon (SOC) and total nitrogen (TN). The soil C: N ratio is often influenced by many factors such as climate soil conditions, vegetation types and agricultural management practices. Soil organic C: N of 20 is generally considered to be a threshold point where either net N mineralization or net N immobilization occurs ((Bowden et al., 2004; Craine et al., 2007 and Alcantara et al., 2013).

MATERIALS AND METHODS

Field experiment was conducted at The Experimental Farm, Fac. of Agric., Al-Azahar Univ., Assuit, located 375 km south Cairo, Egypt (27° 12ˉ 16.67˭ N latitude and 31° 09ˉ 36.86˭ E longitude). The site is characterized by a flat topography and is dominated by well drained Entisols (Soil Survey Staff, 1996) and has clay loam in texture, is slightly alkaline and has low organic matter content but adequate potassium level in the top layers of 50 cm soil depth (Table 1a & b).

The experiment was laid out in split plots design with three replicates and 6 treatments. The study included two nitrogen fertilizer sources and three levels of nitrogen. The main plots were assigned for nitrogen sources (Urea 46.5% N as a fast nitrogen fertilizer and ureaform 40% N as a slow nitrogen fertilizer). The split plots were assigned for nitrogen fertilizer levels as follows: a) at the recommended level (R), b) 15% less than the recommended level (R-15%) and c) 30% less than the recommended level (R-30%). In addition, there is another treatment without nitrogen fertilizer in order to asses the changes in ecosystem in uncultivated soil that could be used as controls for carbon dioxide absorbed from the atmosphere during the season. Soil moisture was adjusted to 65 % of field capacity (FC). The plot area is almost 96 m2 (12 x 8 m2). The previous crop was sunflower.

In the winter season of 2014/15, wheat seeds (Triticum aestivum vulgar. CV Sids 1) were sown on December 7th, consuming 60 kg seed /fed. Phosphorus fertilizer (superphosphate, 15.5% P_2O_5) was broadcasted during soil preparation processes at a rate of 100 kg/fed.

Table 1. Some chemical and physical properties of the soil of the experimental site

a- Physical properties

Soil depth(cm)	Particels size percentage			Texture class	Moisture content(0v %)		A.W. (%)
	Sand	Silt	Clay		F.C.	W.P.	
0-25	26.50	40.00	33.50	Clay Loam	41.00	20.30	20.70
25-50	25.11	39.14	35.75	Clay Loam	40.80	20.00	20.80

F.C. = field capacity W.P. = wilting point A.W. = available water

a- Chemical properties

Soil depth (cm)	OM (%)	$CaCO_3$ (%)	pH (1:2.5)	EC_e (dS/m)	soluble ions (meq/L)							Available nutrients (ppm)		
					CO_3 + HCO_3	CT	SO_4	Ca	Mg	Na	K	N	P	K
0-25	2.43	3.41	7.66	0.95	2.25	1.20	6.00	2.50	1.30	5.24	0.13	70.00	9.63	367.00
25-50	2.13	3.11	7.75	1.10	2.04	1.10	5.60	2.40	1.08	5.07	0.20	56.50	9.55	343.00

O.M. = organic matter pH= soil reaction EC_e = electrical conductivity

Potassium fertilizer (potassium sulphate, 48% K_2O) was added at a rate of 50 kg / fed and it was divided in two equal doses added at the time of nitrogen fertilizer application. Ureaform (slow release nitrogen fertilizer) was added to the soil before sowing at different levels (100 kg, and 85 kg, 70 kg N/ fed). While urea (86 kg, 73 kg and 60 kg N/ fed) was divided in two equal doses added to soil before the 2nd and 3rd irrigation. The plants were harvested 150 days after planting.

Classical chamber method was used for CO_2 emission measurement by trapping in alkali solution, which allows CO_2 fluxes to be measured directly from the soil (Davidson et al., 2002). The measurement chambers (40 cm x 23 cm x 20 cm, length x width x height) covered a soil surface of 0.0874 m2 and had transparent PVC walls. To prevent CO_2 leakage to atmosphere, the chamber was inserted 3 cm into the soil. Soil surface CO_2 flux (Fs) measurements were taken in the daytime between 09:00 and 11:00 hours biweekly using a glass jar filled with 100 ml of sodium hydroxide (1 N). The jars were removed from the chambers, quickly capped, and sent to laboratory for carbon analysis according to Stevenson (1986). Carbon evolved as CO_2 was estimated by the following formula (Stotzky, 1965): mg C as CO_2 = (B – V) x N x E

where:

B = standard acid for the blank (ml)

V = standard acid for fertilizer treatments (ml)

N = normality of standard acid;

E = equivalent weight of C

Soil organic C evolved as CO_2 from soil treated by fertilizer was determined by subtracting the quantity of CO_2–C evolved from control from that evolved from soil fertilizer treatments. Decomposition percentage was estimated by calculating the percentage of the soil organic matter C evolved as CO_2 after correction for the CO_2 evolved from untreated soil according to Ajwa and Tabatabai (1994) using the following equation:

C decomposition % = [(X – Y) / Z)] x 100

Where:

X = C evolved as CO_2 from soil-fertilizer treatments (mg)

Y = C evolved as CO_2 from untreated soil (control); (mg)

Z = C in the soil organic matter (mg)

Soil temperature (Ts) at 5 cm depth and volumetric soil moisture (Ms) measurements were made concurrently with soil surface CO_2 flux (Fs). A soil sample was collected at the surface horizon (0 – 15 cm) to determine the gravimetric soil water content by oven drying at 105°C/24h. Soil surface CO_2 flux is commonly assumed to be exponentially dependant on Ts (Luo and Zhou, 2006), and this temperature is frequently modeled according to Xu and Qi, (2001) using the following equation:

Q_{10} (T) = 1.05- 0.02 T+ 0.045 W

Where:

Q_{10} (dimensionless) is the factorial increase in Fs for every 10 °C rise in Ts

T is a reference soil temperature (°C) at soil surface

W is volumetric soil moisture content (0- 15 cm soil depth).

All measurements have been made during a short period of time in the same ecosystem suggesting that there is no significant influence from phonological differences or different compositions of the respiring pools.

RESULTS AND DISCUSSION

1- Effect of urea fertilizer on soil organic carbon decomposition.

Data presented in Fig. (1) Show the impact of urea fertilizer levels on soil organic carbon decomposition through wheat growing season. It is observed that soil organic carbon decomposition percentage (SOCD) is at a minimum amount in the 1st week and at a maximum amount in the 7^{th} week at the recommended level - 15 % treatment. The biweekly SOCD % recorded at 85 kg N level ranged from 2.37 and 12.24%, while it varied from 0.82 and 9.55 % at 70 kg N/fed level (R-30%). The trend line was less inclined at 70 kg N level than that at 85 kg level. The level of 70 kg N/fed had higher SOCD % than that at 100 kg N/fed in the beginning of the evaluation period (till 5^{th} biweek) but a lower SOCD % at the end.

The addition of urea fertilizer significantly stimulated soil organic carbon decomposition. At the completion of the study, soil organic carbon decomposition as affected by urea fertilizer ranged from 46.16 to 54.90 % at 70 and 100 kg N/fed, respectively. The results indicated that the SOCD % at 70 kg N/fed treatment was less than that at 85 kg N/fed or 100 kg N/fed. Overall, SOCD % followed the order of recommended level > 15% less than recommended level > 30% less than recommended level treatment.

Despite the indirect evidence for N limitation of decomposition, results of direct tests, in which N supply is experimentally increased through fertilization, are inconsistent.

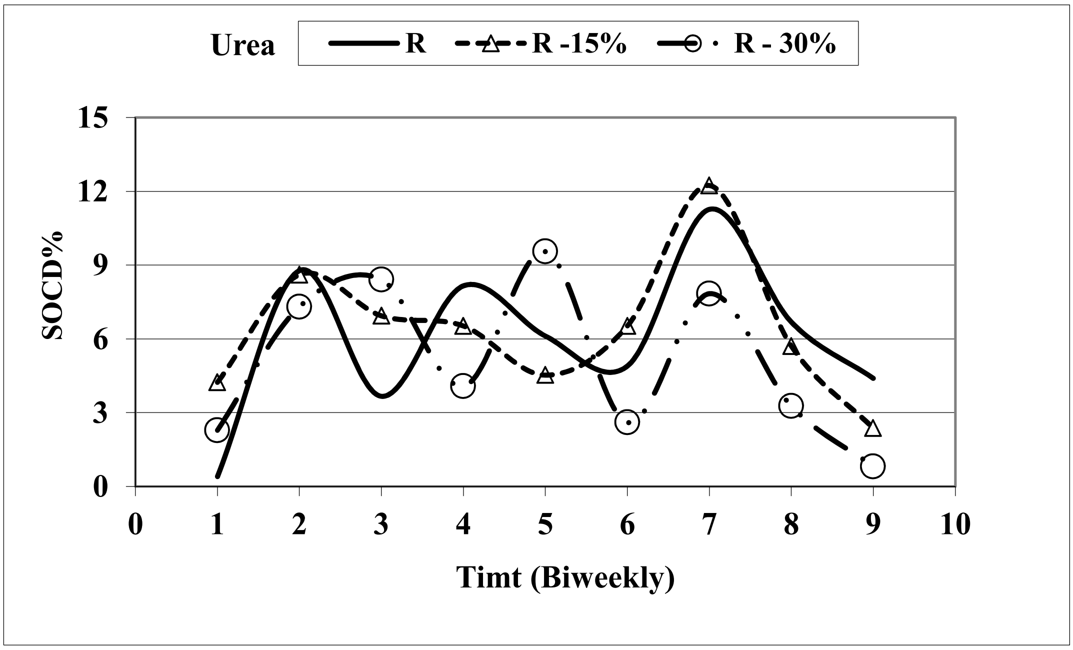

Fig. 1. Soil organic carbon decomposition (SOCD) % in relation to time when soil was fertilized by urea at different levels

A recent meta-analysis of N fertilization effects on decomposition found that N can have stimulatory, neutral, or negative effects on decomposition depending on substrate chemistry, ambient N deposition rates, and the amount of N fertilizer added (Knorr et al. 2005). Specifically, N generally reduced decomposition of substrates with high lignin concentrations but stimulated decomposition of substrates with low lignin concentrations. These results are consistent with those of other studies showing that substrate and/or exogenous N may reduce lignin decomposition either by inhibiting synthesis of ligninolytic enzymes (Sinsabaugh et al. 2002) or by reacting with breakdown products of lignin degradation to form other recalcitrant compounds (Dijkstra et al. 2004).

The effects of N on decomposition may vary, increasing early stages of decomposition (when litter contains relatively high concentrations of labile C and low concentrations of N) but reducing decomposition in its later stages, when the concentrations of lignin in litter have increased. Generally, increases in nitrogen concentration result in faster initial mass losses of organic C, while proportions of more recalcitrant C-compounds increase (Berg, 2000). Kaboneka, S. et al (2004) found that the response of straw C decomposition to N fertilizer addition followed the order: Straw + 120 kg N ha^{-1} = Straw + 80 kg N ha^{-1} > Straw + 40 kg N ha^{-1} > Straw alone.

2- Effect of ureaform fertilizer on soil organic carbon decomposition.

Soil organic carbon decomposition increased as the time proceeded and almost takes the same trend of that at Urea fertilizer (Fig. 2). Soil organic carbon decomposition percent ranged between 0.16- 12.73, 5.14- 10.61 and 0.41- 8.78% for recommended level, 15% less and 30% less than recommended level treatment respectively. It is observed that the amount of soil organic carbon decomposition at treatment of 30% less than recommended level laid down that of 15% less than recommended level treatment along the growing season. The amount of soil CO_2 flux from recommended level treatment was the highest during the entire growing season.

SOCD % as affected by ureaform fertilizer ranged from 37.76 with 30% less than recommended level, 65.53 with 15% less than recommended level to 67.22% with recommended level. No significant differences were observed between treatments fertilized with 15% less than recommended level and recommended level. Overall, soil organic carbon decomposition % followed the order: recommended level > 15% less than recommended level > 30% less than recommended level.

Increases in nitrogen deposition have been shown to affect soil carbon storage positively, because they reduce saprotrophic respiration via mechanisms that shift the composition of the OM towards more chemically stable compounds.

High N content also appears to suppress activities of ligninolytic fungi and their enzymes (Janssens et al., 2010; Liu & Greaver, 2010). However, N has complex effects in decomposition processes as high N concentrations appear to enhance degradation in early stages of fresh litter decomposition but suppress it in late stages (Berg, 2000). Thus, it plays a key role in the sequestration of soil carbon. Because of the importance of carbon sequestration for the climate, the interactive effects of soil N content and temperature on the temperature sensitivity of CO2 production from OM decomposition is a very important issue.

3. Effect of soil temperature on soil organic carbon decomposition.

It is observed that there is a positive relationship between soil organic carbon decomposition and temperature sensitivity (Q_{10}) through wheat growing season when the soil fertilizered by urea or ureaform (Fig. 3).The highest values of SOCD % were 8.4 and 8.2 at 2.4 Q_{10} value with urea and at 2.7 Q_{10} value with ureaform, respectively. The lowest values of SOCD % were 2.3 and 4.4 at 2.2 Q_{10} value with urea or ureaform, respectively. It is obviously that the SOCD rate was higher under ureaform treatment than that under urea treatment.

Giardina and Ryan, (2000), found that the decomposition of stable compounds (low quality carbon) is not temperature sensitive. Fang et al. (2005) and Conen et al. (2006) stated that both labile and stable organic compounds respond similarly to temperature increases and some of the more recent studies have found that the temperature sensitivity increases with decreased quality of the organic matter (OM). The highly significant decrease in the negative effect of nitrogen on saprotrophic CO_2 production with decreasing temperature might also importantly help to explain much of the controversy in the scientific literature on the effects of nitrogen on OM decomposition. This positive correlation is contrary to expectations based on the carbon quality theory, which only accounts for carbon quality and predicts that the temperature sensitivity of saprotrophic decomposition of OM should increase as the activation energy of the relevant enzymatic processes rises (Davidson & Janssens, 2006; Janssens et al., 2010 and Wetterstedt et al., 2010).

4- Soil organic carbon (SOC), nitrogen content and C: N ratio

Data presented in Fig. (1) Show the influence of nitrogen fertilizer (type and level) on soil C: N ratio. In general, soil C: N ratio values under all treatments were higher than that of initial state except that under 30% less from the recommended level of urea (Fig.4). The recommended level showed almost the same soil C: N ratio at urea or ureaform treatment (Fig.4). The soil C: N ratio was higher at 15% less from the recommended urea level than that when soil treated by ureaform. The opposite trend is true at 30% less from the recommended level.

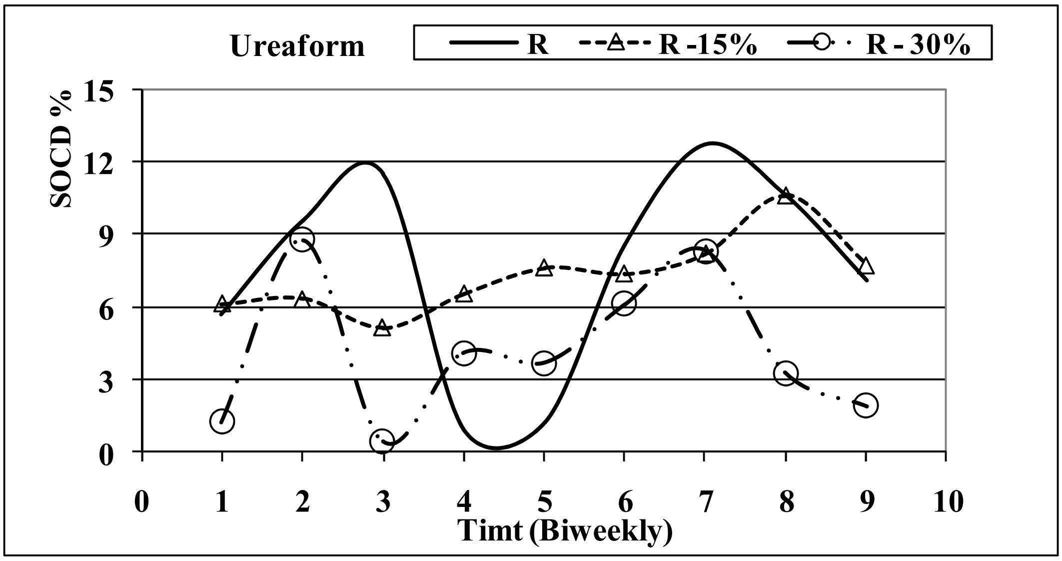

Fig. 2. Soil organic carbon decomposition (SOCD) % in relation to time when soil was fertilized by ureaform at different levels

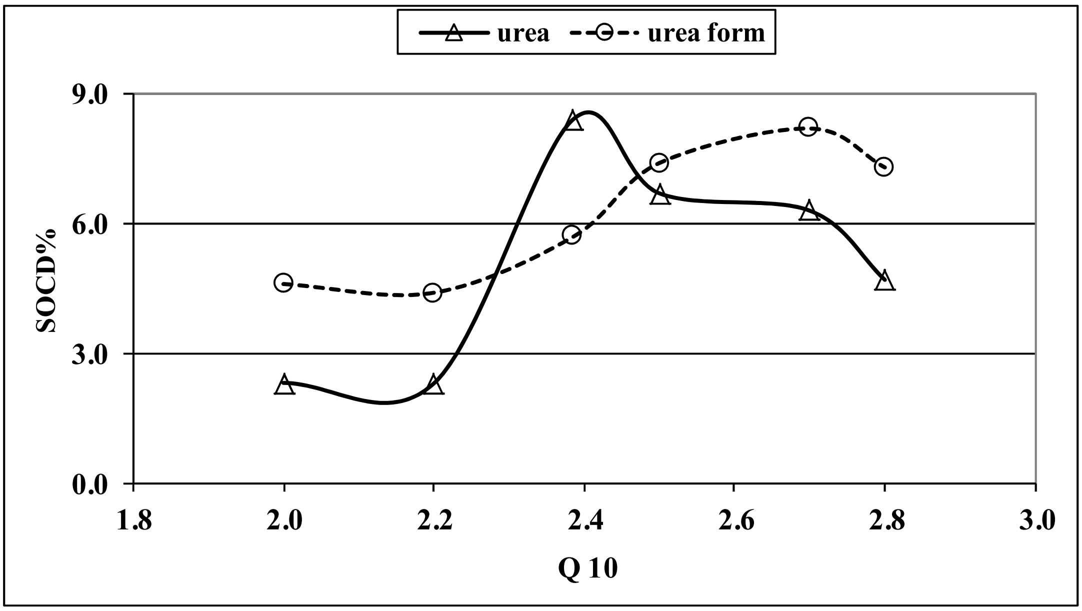

Fig. 3. Soil organic carbon decomposition (SOCD) % in relation to Q_{10} when soil fertilized by urea and ureaform through wheat growing season

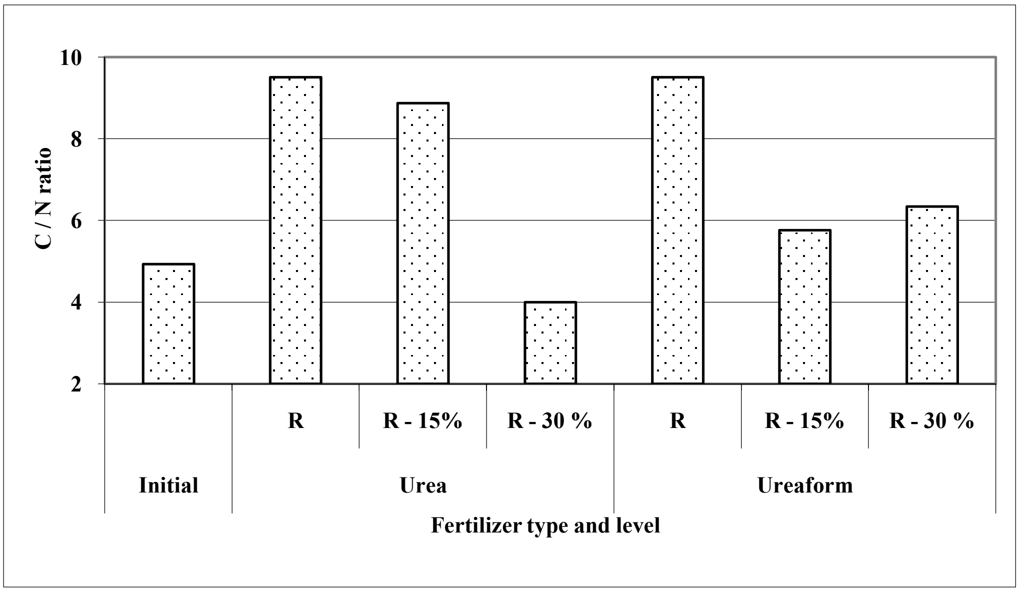

Fig.4. Soil C: N ratio in relation to urea and ureaform fertilizer through wheat growing season

Soils present low organic carbon content due to the high mineralization of the organic matter and the absence of harvest residues after periods of drought. On the contrary, soils with tree coverage show an increase in carbon and nitrogen (Albretch and Kandji, 2003). Additionally, residue retention can increase the proportion of SOC with a lower decomposition degree and higher C: N ratio. Thus, even a relatively small increase or decrease in soil carbon content due to changes in management practices may result in a significant net exchange of C between the soil C pool and the atmosphere.

Higher clay content is often associated with more decomposed organic matter with a lower C: N ratio and crop residues could favour a higher soil C: N ratio. Also, C: N ratios might vary between 8:1 and 15:1, with an average of 12:1 (Houghton, 2003; Puget & Lal, 2005; Yamashita et al., 2006; Brady & Weil, 2008 and Xu et al., 2011).

It may be concluded that nitrogen fertilization increases soil organic carbon decomposition but at different rates especially at high level. Ureaform as a slow release nitrogen fertilizer might slow down organic carbon decomposition which could consider a positive effect. There is other factors might be responsible or control soil organic decomposition such as temperature and C: N ratio. If the applied organic material contains more nitrogen in proportion to the carbon, then nitrogen is released into the soil from the decomposing organic material.

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الملخص العربي

تأثير التسميد النيتروجيني علي تحلل الكربون العضوي في التربة

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أجريت تجربة حقلية بالمزرعة التجريبية لكلية الزراعة جامعة الازهر بأسيوط والتي تقع علي بعد ٣٧٥ كم جنوب القاهرة وعند خط عرض 27° 12' 16.67" شمالا وخط طول 31° 09' 36.86" جنوبا خلال موسم محصول القمح (٢٠١٥) بهدف تقييم تأثير نوع السماد النيتروجيني (اليوريا، اليوريا فورم) عند معدلات مختلفة علي تحلل الكربون العضوي في التربة.

أوضحت النتائج أن النسبة المئوية لتحلل الكربون العضوي في التربة كانت أقل في الأسبوع الثاني وأقصي في الأسبوع السابع مع سماد اليوريا عند اضافة الكمية الموصي بها وكانت ١٥% أقل من الكمية الموصي بها. كانت تتراوح النسبة المئوية لتحلل الكربون العضوي في التربة بين ٠,١٦– ١٢,٧٣ و٥,١٤ – ١٠,٦١ و٠,٤١ – ٨,٧٨% مع سماد اليوريافورم عند ١٥ % و٣٠ % أقل من الكمية الموصي بها والكمية الموصي بها علي التوالي. وكانت كمية ثاني أوكسيد الكربون المنبعثة من التربة مع معاملة اليوريافورم عند اضافة الكمية الموصي بها أعلي خلال موسم النمو. وعموما فان النسبة المئوية لتحلل الكربون العضوي في التربة يمكن ترتيبها تصاعديا كالاتي: الكمية الموصي بها> ١٥%> ٣٠% أقل من الموصي بها. أعلي قيم للنسبة المئوية لتحلل الكربون العضوي في التربة كانت ٨,٤ و٨,٢ عند $Q_{10} = 2.4$ مع سماد اليوريا وعند Q_{10} =2.7 مع سماد اليوريافورم. وكانت أقل قيم للنسبة المئوية لتحلل الكربون العضوي في التربة هي ٢,٣ و٤,٤ عند Q_{10} =2.2 مع اليوريا أو اليوريافورم علي التوالي.

قيم نسبة C:N في التربة تحت كل المعاملات كانت أعلي من الحالة الأساسية للتربة ماعدا معاملة اليوريا عند ٣٠% أقل من الكمية الموصي بها. قيم نسبة C:N في التربة كانت عالية عند اليوريا ١٥% أقل من الكمية الموصي بها عن معاملة التربة باليوريافورم. والعكس صحيح عند ٣٠% أقل من الكمية الموصي بها.