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Barley Yield and Nitrogen Derived by Plants from Mineral and Organic Fertilizers with Application of ^{15}N Stable Isotope.

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ABSTRACT

A field experiment was carried out with constructed drip irrigation system on sandy soil to recognize the most proper nitrogen fertilization strategy that could be more benefits for barley production taking into consideration the economical and environmental impacts. Barley crop was significantly positively affected by nitrogen fertilizer rates and organic compost. Grain yield (45%) and shoot (11%), root (36%) dry weight were relatively increased with increasing N fertilizer rate. Plants fully fertilized with organic compost showed relative higher grain yield than those either received 100% or 50% N-mineral fertilizer which accounted for 37%. In this case, shoot and root dry matter yield were nearly closed to those of 50% N-fertilizer, but to some extent lower than those of 100% N-fertilized treatment. Plants treated with fully organic compost achieved N uptake by grains nearly closed to those obtained with high N fertilizer rate (70 kg N fed^{-1}). Combined treatment of organic plus mineral-N did not reflect significant differences than those of plants fertilized with half N fertilizer dose. Portion of nitrogen derived from fertilizer (Ndff) and absolute value reflected higher values and percentage at rate of 100% fertilizer than those induced by 50% N rate. Ndff by grain, shoot and root of combined treatment were nearly closed to those achieved by 50% mineral-N rate. More nitrogen was derived from organic compost and still higher in grain than shoot and root systems. Nitrogen added at half dose combined with organic compost was efficiently used by grain and root recording values nearly closed to those recorded with plants treated by half mineral-N rate.

Keywords: Barley, isotope dilution, mineral-N, ^{15}N, N-rate, organic compost

INTRODUCTION

Historical background about the importance of barley written by Langridge (2018) indicated its interesting history. It is thought to be the first crop domesticated and developed as the staple food for the earliest farmers. While, production for the other major cereal crops, maize, rice and wheat, has continued to grow, barley production has stagnated over the past two decades. Today, barley is grown across the temperate regions of both the northern and southern hemispheres. Among cereals, barley came to the third position after wheat and maize (FAO 2011).

Proper nitrogen fertilization strategy is a limiting factor. Therefore, improvement of N efficiency is essential target in barley research. This target was found to be affected by many factors related to management, soil and plant itself (Andersson and Holm 2011). Enhancement of N fertilizer utilization in addition to those recovered from the soil may allow farmers to use moderate N quantities and in the same time achieved remarkable yield (Anbessa and Juskiw 2012, Bingham *et al.* 2012). Excess of nitrogen not utilized by plant and residue in soil may be exposed to losses via volatilization, denitrification and leaching (Cassman *et al.* 2002). Only 30-50% of applied nitrogen fertilizer is taken up by crops (Dobermann 2005), hence the improvement in NUE is important to reduce input costs and the negative impact of excessive N on the environment (Snyder 2009, Anbessa and Juskiw 2012). Barley yields were about 68% higher at NPK fertilization and 55% at N-mineral + ST (5 t ha^{-1} spring barley straw) in comparison with unfertilized control. The highest nitrogen use efficiency of mineral fertilizers was recorded with farm yard manure application (Shejbalová *et al.* 2014).

Montemurro *et al.* (2006) showed that nitrogen fertilization at the start of cultivation plus organic N forms has a positive effect on yield component and induced good balance between productive parameters, N utilization efficiency indices and soil N deficit. Farmyard manure (FYM) plays an important role in supplying plant nutrients and enhancing soil productivity; soil organic carbon and available P and K contents increased with the application of FYM (Singh *et al.*, 2000).

Kas *et al.* (2010) concluded similar positive effect of cereal straw and farmyard manure on barley yield. The combined application of chemical fertilizer and maize straw with a wide C/N ratio is an important way of reducing the superfluous accumulation of N fertilizer (Lu *et al.*, 2010).

Therefore, this work aims to recognize the proper management of both organic and mineral-N fertilization in field conditions for optimizing barley yield and enhancement of nitrogen use efficiency either applied in organic or mineral form.

MATERIALS AND METHODS

Site description

Winter barley seeds (*Hordeum vulgare* L.) Giza 127 were sown in the 2014/2015 cropping season in the research field of the Soil and Water Research Department, Nuclear Research Center, Atomic Energy Authority, Sharqeia Governorate, Egypt. The soil of the study site (located at latitudes30◦07'51" and 30◦14'57.33" N, and longitudes 31017'41.54" and 31021'11.19" E.) was classified as a sandy loam soil containing 79% sand, 15% silt and 6% clay. The sandy loam soil had low initial organic matter (0.035%), pH (7.8) and fairly low nitrogen content (0.02−0.03%). Soil samples were analyzed according to Carter and Gregoreish (2008). This experiment was carried out to evaluate the effect of mineral fertilizer (^{15}N-labelled ammonium sulfate 2% atom excess) either added solely or in combinations with organic compost in different ratios. Organic compost was composed from Leuceana residues and cattle manure collected from our own farm located at Inshas area, mixed in 1:1 ratio (W/W) and composted in cement tanks for two months then samples of composted materials were taken for chemical analysis (Table 1). Analysis of composted materials was carried out according to Carter and Gregoreish (2008). The experimental treatments were arranged in Complete Randomized Block Design (CRBD) under field conditions.

Table 1. Some chemical constituents of locally made compost.

Determinants	Compost
pH (1:5)	7.00
EC ds m^{-1}	3.60
C/N ratio	12.63
O.M%	60.34
N %	0.50
P %	0.74
K %	0.808
Microelements µg g^{-1}	
Fe	2859.2
Cu	205.92
Mn	184.52
Zn	166.88

Basically, the recommended doses of phosphorus and potassium were applied to the experimental soil before cultivation. Phosphorus was applied at rate of 100 kg P fed^{-1} (equal to 240 kg ha^{-1}) in the form of triple super-phosphate, while potassium was added at rate of 50 kg K fed^{-1} (equal to 120 kg ha^{-1}) in the form potassium sulfate. Nitrogen was added in different rates either solely or in combinations with different rates of compost.

Fertilization treatments were: 100% recommended rate of labeled ammonium sulfate; 50% recommended rate; 100% organic compost; and 50% ammonium sulfate plus 50% Organic compost.

The experiment had a factorial arrangement with two levels of mineral N (70 and 35 kg fed^{-1}, referred to as N100, N50, respectively). Nitrogen levels N100 and N50 were applied after seedlings initiation either individually or plus organic compost, while organic compost was incorporated into the soil 30 days before cultivation. The two levels of N fertilizer and organic compost were applied in three replicates. There were a total of 12 plots, each with a gross area of 48 m^2, under drip irrigation system.

Plant analyses were carried out according to Estefan et al, (2013), while $^{15}N/^{14}N$ ratio analysis was carried out using emission spectrometer model NOI-6PC following the information after IAEA, (2001). The following standard equations were used for estimation of nitrogen derived from fertilizer (Ndff), organic compost (Ndforg) and nitrogen use efficiency (%NUE).

$$\%\ Ndff = \frac{^{15}N \text{ atom excess in sample}}{^{15}N \text{ atom excess in fertilizer added}} \times 100$$

$$\%\ NUE = \text{Ndff yield/N fertilizer rate} \times 100$$

$$\%\ Ndforg = \frac{^{15}N \text{ atom excess in untreated with organic}}{^{15}N \text{ atom excess in treated with organic}} \times 100$$

$$\text{Fertilizer-N\% remained in soil} = \frac{^{15}N\% \text{ a.e. in soil sample}}{^{15}N\% \text{ a.e. in added fertilizer}} \times 100$$

All the obtained data were subjected to ANOVA analysis followed by Duncan's multiple range test (DMRT) for comparison between means using SAS software program (2002).

RESULTS AND DISCUSSION

Growth and yield

Barley plants fertilized with full N dose produced higher grain yield over those fertilized with the half dose (Table 2). Increments were relatively accounted for 45% over those received 50% N-fertilizer rate. Shoot dry matter yield of fully fertilized plants recorded a relative increase by about 11% over those received half N-fertilizer rate. Similar trend, but to somewhat higher extent (36%), was observed in case of root dry matter yield. Both shoot and root systems noted lower dry matter yield than the grain yield. Plants fully fertilized with organic compost showed relative higher grain yield than those either received 100% or 50% N-mineral fertilizer which accounted for 37%. In this case, shoot and root dry matter yield were nearly closed to those of 50% N-fertilizer, but to some extent lower than those of 100% N-fertilized treatment. The best grain yield as affected by fertilization treatments was recorded with combination of mineral N-fertilizer and organic compost at 50:50 rates. It was relatively increased by about 40%, 102% and 2% over fully mineral-N, half mineral-N and fully organic compost, respectively. It means that fully organic treatment and combined one were nearly closed to each other. From an economical view, we can recommend the full organic treatment. Due to findings of Berhanu *et al.*, (2013), barley grain and straw yields were significantly increased with increasing N mineral fertilizer from 40 up to 120 kg ha^{-1}, and then tended to decrease. They recorded relative increase by about 68.4% in the grain yield (GY) of barley at 40 kg N ha^{-1} and 89.4% at 80 kg N ha^{-1}. These findings are nearly closed to those we have.

Table 2. Effect of organic and mineral fertilization on growth and grain yield of barley crop (kg fed^{-1}).

Treatments	Dry weight kg fed^{-1}			
	Grain	Shoot	Root	Shoot + Root
Mineral-N %				
100	1890ab	639bc	564c	1203
50	1305b	577bc	415c	992
Organic compost 100%	2595a	555bc	465c	1020
%Mineral+%compost				
50M+50 C	2649a	587c	325d	912

Means followed by the same letter in the same column are not significantly different at ($P \leq 0.05$)

Also, they found that the application of organic fertilizer sources greatly enhanced the grain yield and yield components. Their results confirmed our results since the application of farm yard manure and residues achieved higher grain yield than those fertilized with mineral-N at different rates up to 120 kg N ha^{-1}.

Our findings proved that the integration between organic and mineral fertilizers could be more beneficial than the individual treatments. Similar results were also reported on barley (Agegnehu *et al.* 2016; Assefa 2015), wheat (Demelash *et al.* 2014; Getachew *et al.* 2014), tef (Getachew *et al.* 2014), maize (Mahmood *et al.* 2017; Wakene *et al.* 2005), Okra (Afe and Oluleye 2017) and tomato (Rajaie and Tavakoly 2016). This phenomenon may be attributed to positive changes of soil characteristics and nutrients availability (Tadesse *et al.*, 2018).

Nitrogen uptake by barely grains (Table 3) was significantly increased with application of 100% N rate (70 kg N fed^{-1}) comparing to the half dose (35 kg N fed^{-1}). It was relatively increased by about 30% over those induced by half N dose. Similar trend, but to somewhat lower extent, was noticed with both shoot and root organs. Plants treated with fully organic compost achieved N uptake by grains nearly closed to those obtained with high N fertilizer rate (70 kg N fed^{-1}). Similar trend, but to low extent, was detected for shoot and root. Combined treatment of organic plus mineral-N did not reflect significant differences than those of plants fertilized with half N fertilizer dose. This holds true for all plant parts.

On line, Berhanu *et al.*, (2013) recorded increments in nitrogen uptake with increasing rates of N fertilizer application, up to 120 kg N ha^{-1} in the grain and up to 160 kg N ha^{-1} in the straw. Residue additives found to be effective in increasing N uptake but the values were nearly closed or slightly lower than those of N fertilizer application. It could be that the crop residues as organic additives stimulated the soil microbial community, which in turn affected N mineralization and soil organic carbon (SOC) (Bending *et al.*, 2002).

An explanation of N uptake enhancement by combined treatment (50 M + 50 C) was reported by (Banik and Sharma, 2009) who indicated that organic and inorganic nutrient sources may enhanced the grain yield and biomass production. The use of organic sources nourished soil nutrients and built up soil organic matter (Berzsenyi *et al.*, 2000; Kismányoky, 2009). In consistent, the complementary application of straw (organic source) and other residues was important for winter barley. The incorporation of straw into the soil can reduce dependence on mineral N fertilizer and return significant nutrients and SOC to the soil in the long term, therefore reducing fertilizer costs, lowering environmental risks and promoting sustainable production (Berhanu *et al.*, 2013).

Soil enzymes and respiration activities in soil rhizosphere as well as nutrient uptake by barley plants may be enhanced by organic fertilization (Liang *et al.*, 2005).

Table 3. Effect of organic and mineral fertilization on N uptake (kg fed^{-1}) by grain, shoot and root of barley crop.

Treatments	N uptake kg fed^{-1}			
	Grain	Shoot	Root	Shoot + Root
Mineral-N %				
100	32.9a	30.2ab	14.7c	49.9
50	25.3b	21.5b	8.6cd	30.1
Organic compost 100%	33.4a	29.6ab	13.7c	43.3
%Mineral+ %compost				
50M+50 C	25.4b	22.7b	9.3cd	49.0

Means followed by the same letter in the same column are not significantly different at ($P \leq 0.05$)

Nitrogen derived from chemical fertilizer and organic form was differentially affected by addition rates (Table 4). Portion Ndff and absolute value reflected higher values and percentage at rate of 100% fertilizer than those indicated with 50% N rate. This holds true with all plant parts but it was higher in grain than shoot and root, respectively.

Table 4. Effect of organic and mineral fertilization on N derived from fertilizer and organic compost (%& kg fed^{-1}) by grain, shoot and root of barley crop.

Treatments	N derived from fertilizer Ndff					
	Grain		Shoot		Root	
	%	kg	%	kg	%	kg
Mineral-N %						
100	83.5	27.5	51.0	18.0	23.5	3.5
50	48.0	12.1	47.5	10.2	17.0	1.5
%Mineral+ %compost						
50M+50 C	47.0	11.9	40.0	9.1	17.0	1.6
	N derived from organic compost Ndforg					
	53.0	13.5	60.0	13.6	83.0	7.7

In case of combined treatment, Ndff by grain, shoot and root showed percentages and absolute values nearly closed to those indicated with 50% mineral-N rate. In this respect, more nitrogen was derived from organic compost and still higher in grain than shoot and root systems.

Shejbalová *et al.*, (2014) found greater efficiency of nitrogen from organic fertilizers than mineral form. In the same direction, higher values of nitrogen efficiency (NUtE) achieved by organic fertilization (Angás *et al.* 2006). This may be attributed to lower available nitrogen.

Mineral nitrogen use efficiency (NUE) was slightly high in grain of plant treated with full recommended rate comparing to those treated with the half recommended rate (Table 5). Average of mineral fertilization treatments showed high NUE% in grain followed by those of shoot while root reflected very poor NUE. Nitrogen added at half dose combined with organic compost was used by grain and root at NUE values nearly closed to those recorded with plants treated by half mineral-N rate. In contrast, those used by shoot of plant treated with 50% mineral-N was higher than those received half dose in combination with organic compost.

Table 5. Effect of organic and mineral fertilization on NUE (%) used by grain, shoot and roots of barley crop.

Treatments	%NUE		
	Grain	Shoot	Root
Mineral-N %			
100	39.3	25.7	5.0
50	34.6	34.6	4.3
%Mineral+ % compost			
50M+50 C	34.0	26.0	4.6

Our results were nearly closed, especially in grain, to those of Shejbalová *et al.*, (2014) who recorded higher nitrogen recovery (60.3%) with combined treatment (mineral-N + straw ST) than those of only mineral fertilized plants (46.2%). Similar trend was recorded earlier (Snyder 2009; Ladha *et al.* 2005).

Gadalla *et al.*, (2008), concluded that the incorporation of leucaena residues and compost either individually or in combination have a positive role on enhancement of fertilizer-N utilization and consequently its recovery by barley plant which was altered. Farahani *et al.*, (2011) explained that the steep slope of N increment in vermicompost treatments could be because of relatively higher mineralization rate at drought stress conditions which provide more available nitrogen to be absorbed by the plant, causing a more nitrogen concentration in the barley grain.

In addition, Tadesse *et al.*, (2018) stated that integrated management of organic and mineral fertilizers achieved high yield of barley and enhanced grain quality and soil fertility. This is recommended for sustainable malting barley production. Their findings are quite different than results we have.

Nitrogen remained in soil and N fertilizer balance

Portion and absolute values of fertilizer-N remained in soil after harvest and fertilizer-N balance as affected by fertilization treatments are presented in Table (6). Grain was gained more nitrogen from fertilizer added at rate of 70 kg N fed^{-1} (100%), therefore, little quantities of fertilizer-N was left in the soil after harvest and also small percent was lost by any mechanism from the soil. Medium amounts of fertilizer-N were derived from fertilizer to grain and the rest was divided between those remained in soil and others lost where both were nearly closed to each other when plants treated with half N dose (50%). More fertilizer-N was remained in the soil after harvest against small budget lost from the soil under combined treatment of mineral plus organic fertilizers.

Table 6. Effect of chemical fertilizer and organic amendments on fertilizer-N remained in soil and nitrogen fertilizer balance (%) under barley plants.

Treatments	Fertilizer-N Balance (%)											
	Plant organs											
	Grain				Shoot				Root			
	NR%	NR kg	NF%	NL%	NR%	NR kg	NF%	NL%	NR%	NR kg	NF%	NL%
100	8.5	5.9	83.5	8.0	8.5	5.9	51.0	40.5	8.5	5.9	23.5	68.0
50	27.5	9.6	48.0	24.5	27.5	9.6	47.5	25.0	27.5	9.6	17.0	55.5
50M+50 C	41.0	14.4	47.0	12.0	41.0	14.4	40.0	19.0	41.0	14.4	17.0	42.0

NR, N remained in soil; NF, N gained from fertilizer; NL, N fertilizer losses

In case of shoot, more fertilizer-N was lost from the soil when plants treated with 100% recommended rate. It decreases with decreasing fertilizer-N rate up to 50% of the recommended rate. In this respect, the lowest percent of N losses was detected with application of the combined treatment (19%). Similar trend, but to somewhat higher extent, was detected with root system.

This result is lies between ranges of Smith and Gyles (1988) who found that nitrogen fertilizer remained in the soil, including that in roots, accounted for 56 to 35%. Barley treated with different nitrogen rates under different water regimes reflected decreases in fertilizer-N remained in soil after harvest with low N rate comparing to the highest rates (Gaber *et al.*, 2017). Nutrients are limiting factor via providing economically optimum nourishment to the crop. On the other hand, reduction of nutrient losses leads to support agricultural system sustainability through contributions to soil fertility or other components of soil quality (Mikkelsen *et al.*, 2012). In this regard, Samak *et al.*, (2016) found that nitrogen recovered by barley crop showed significant correlation with nitrogen added rates.

CONCLUSION

It is clear that compost application plus 35 kg N fed^{-1} boosted yield, grain nitrogen concentration, comparable to individual treatments. It proves that barley grain yield more benefited from organic compost plus mineral-N than individual additions. Combined treatment of organic compost and mineral fertilizer achieved high amount of mineral-N remained in soil and this may be benefits for the succeeding crop in the rotation, in the same time decline the amount of nitrogen losses. The data of $^{15}N/^{14}N$ ratio analysis proved this result and gave us the chance to recommend the integrated nitrogen management of organic and mineral forms as a proper strategy under the given conditions.

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انتاجية الشعير والنيتروجين المستمد من الأسمدة المعدنية والعضوية مع تطبيق النظير المستقر – نيتروجين-15 .

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أجريت تجربة حقلية تحت نظام الري بالتنقيط في أرض رملية بغرض تمييز استراتيجيات التسميد الأكثر ملائمة وفائدة لإنتاج الشعير مع الأخذ في الاعتبار العوائد الاقتصادية والبيئية. تأثر نبات الشعير معنويا وايجابيا بمعدلات النيتروجين والكمبوست العضوي. انتاجية الحبوب والوزن الجاف لكل من السيقان والجذور زادت نسبيا بمقدار 45%، 11%، 36% على الترتيب مع زيادة معدل النيتروجين السمادى. أظهرت النباتات المسمدة بالجرعة الكاملة من السماد العضوي زيادة نسبية عالية في انتاج الحبوب عن تلك المسمدة بمعدل كامل من السماد المعدني أو تلك المسمدة بنصف الجرعة مسجلة 37%. في هذا الصدد, كانت انتاجية المادة الجافة من السيقان والجذور قريبة من تلك المسجلة، ولكن بمدى أقل، مع النباتات المسمدة بالجرعة الكاملة من السماد المعدني. حققت النباتات المسمدة بالكمبوست امتصاص للآزوت بواسطة الحبوب قريبا لتلك المسجلة مع معاملة التسميد المعدني الكاملة (70 كجم ، للفدان).المعاملة المختلطة لم تحقق اختلافا معنويا عن تلك المسمدة بنصف الجرعة السمادية. النسب المئوية والقيم المطلقة للآزوت المستمد من السماد المعدني كانت أعلى في حالة النباتات المسمدة بالجرعة الكاملة عن تلك المسمدة بنصف الجرعة. النيتروجين المستمد بواسطة الحبوب والسيقان والجذور للنباتات المعاملة بالتسميد المختلط كان أقرب ما يكون للنباتات المسمدة بنصف الجرعة السمادية. كثير من النيتروجين أستمد من الكمبوست العضوي وكان أعلى في حالة الحبوب عن السيقان والجذور. النيتروجين المضاف بنصف الجرعة في مخلوط مع الكمبوست العضوي أستغل بكفاءة بواسطة الحبوب والجذور مسجلا قيم أقرب ما تكون الى تلك المسجلة مع النباتات المسمدة بنصف الجرعة السمادية.