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Nitrogen Distribution in Soil Profile under Sesame, Maize and Wheat Crops as Affected by Organic and Inorganic Nitrogen Fertilizers Using ^{15}N Technique

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Nitrogen remained in soil and distributed along the soil profile of virgin sandy soil after sesame, maize and wheat were examined using ^{15}N isotope dilution concept. A field experiment was conducted on virgin sandy soil at the farm station of Soil and Water Research Department, Nuclear Research Center, Inshas, Egypt. Treatments of organic and inorganic fertilization practices were arranged in a complete randomized block design with three replications under drip irrigation system. After harvest of wheat, sesame and maize crops, nitrogen remained in soil was examined using the ^{15}N isotope dilution concept. Results indicated that nitrogen uptake was positively affected by fertilization sole or combined treatments and significantly vary according to crop and different plant organs. Fertilizer N balance showed that the proportion remained in soil after harvest was differentiated dependable on crop and rate of application. In this regard, combined mineral-

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organic fertilization practice reflected significant reduction in N remained in soil after harvest. Nitrogen remained after maize was higher than those after wheat and sesame, respectively. Mineral-organic fertilization reduced the proportion of N fertilizer lost from the soil media. These losses were attributed to the tested crop and significantly vary among them. N remained in soil was distributed in depth of 0-20, 20-40 and 40-60 cm without significant difference between depths under sesame while wheat showed accumulation in 0-20 cm depth. N remained under maize showed accumulation in 0-20 cm affected by the combined application of 50% compost commercial +50% nitrogen mineral fertilizer (50%C2+50%MF).

Keywords: Nitrogen; organic manure; ^{15}N technique; sesame; maize; wheat.

1. INTRODUCTION

Nitrogen is the key factor in plant nutrition and considered as a major nutrient that influence the crop production. The method using ^{15}N-labelled plant materials has been useful for direct estimation of plant N uptake from the green manures (GMs). Earlier studies have found that the N uptake by the subsequent crop was 6–25% of the input ^{15}N labeled GM, hairy vetch, ryegrass, phacelia, white clover, red clover subterranean clover, field bean, and timothy in upland soils [1,2,3,4,5], and 19–50% of the ^{15}N labeled GMs sesbania and maize applied in paddy soils [6,7,8].

The present work is aimed to trace the distribution and balance of N-fertilizer either added solely or in combination with organic residues those applied for improving sesame, wheat and maize production grown on field scale under drip irrigation system and virgin sandy soil.

2. MATERIALS AND METHODS

Field experiment was conducted at the experimental station of Soil and Water Research Department, Nuclear Research Center, Atomic Energy Authority, Abou-Zaabl. Chemical and physical characteristics of experimental soil are presented in Table 1. Analysis on experimental soil were carried out according to [9]. Different crops, i.e. sesame, wheat and maize were cultivated under drip irrigation system.

2.1 Tested Crops

Seeds of Sesame (*Sesamum indicum* L c.v. Shandaweel3), Maize (*Zea mays* c.v. Hybrid one 10), supplied by the Agriculture Research Centre (ARC), Giza, Egypt and seeds of Wheat (*Triticum sativum* c.v. Gmiza 9) cultivars were used.

2.2 Organic Materials

Cattle manure (C3) and two locally composted plant residues were used as organic fertilizers. Commercial compost 2 (C2) was provided by industrial company while compost 1 (C1) was locally prepared by the staff of Atomic Energy Authority, Soil and Water Department. Organic materials were air-dried, ground and subjected to chemical analysis (Table 2).

2.3 Mineral Fertilizer

^{15}N-Labeled ammonium sulfate with 2% ^{15}N atom excess was applied as a source of mineral nitrogen (ammonium sulfate) at different rates depending on tested crop once after four weeks from planting.

Table 1. Some physical and chemical properties of experimental soil

Coarse sand%	**Fine sand %**	**Silt%**	**Clay%**	**Texture**			
64.1	26.4	2.7	6.8	Sandy			
Cations				**Anions**			
Soluble cations and anions (meq 100 gm^{-1} soil)							
Ca^{2+}	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**CO_3^{2-}**	**HCO_3^{-}**	**Cl^{-}**	**SO_4^{2-}**
1.25	1	0.32	0.09	----	0.88	1.25	0.53
pH (1: 2.5)	**EC (dSm^{-1})**	**O.C %**	**O.M %**	**T. N %**	**C/N Ratio**	**$CaCO_3$ %**	
7.97	0.27	0.017	0.03	0.007	2.43	1.0	

Table 2. Some chemical characteristics of the tested organic materials

Value	Compost local	Compost commercial	Cattle manure
pH (1:5)	6.70	6.14	6.68
EC dSm^{-1}	12.7	12.3	13.3
C/N ratio	12.6	15.3	26.0
O.M%	56.89	43.10	39.89
N %	2.83	1.63	0.89
P%	0.84	1.21	0.53
K %	0.69	0.97	0.51
Total Fe($\mu g\ g^{-1}$)	2898	1586	2730

2.4 Field Experiment Layout

A field experiment was carried out according to complete randomized block design with three replicates under drip irrigation system. Seeds were planted as recommendation of Agriculture Research Centre, Giza, Egypt.

The experiment is consisted of 21 treatments for each crop. These treatments includes one treatment of 100% Mineral fertilizer (control), three treatments of 100% organic manure and three treatments of 50% organic manure + 50% Mineral fertilizer (MF). The treatments could be explained in details as follows:

T1 = 100% MF (ammonium sulfate),
T2 = 100% C1 (local compost);
T3 = 50% C1 + 50% MF,
T4 = 100% C2 (commercial compost);
T5 = 50% C2 + 50% MF;
T6 = 100% C3 (cattle manure);
T7 = 50% C3 + 50% MF.

A basic supplemental doses of N fertilizer was applied to each plots (2.25 x 10 m^2) at the rate of 100 kg fed^{-1} (equal 240 kg N ha^{-1}) as organic manure or mineral fertilizer (ammonium sulfate) of wheat, while sesame received 45 kg fed^{-1} and maize supplied with 120 kg fed^{-1}. The phosphorus and potassium were applied at rate of 30 kg P_2O_5 and 24 kg K_2O as phosphoric acid and potassium sulfate, respectively.

Sesame, maize and wheat crops were uprooted at harvest (120 days for maize and sesame, and 240 days for wheat) and separated into shoot, root and grain. Plant samples were subjected to chemical analysis according to [10]. The following parameters were analyzed and estimated:

Plant nitrogen uptake; Nitrogen derived from fertilizer (Ndff) and Nitrogen remained in soil (Nrem). N content in soil and plant was determined using the Kjeldahl method.

^{15}N-analysis: The Dumas dry combustion was used to convert the nitrogen compounds in the dry samples into nitrogen gas. In this method, all the organic or inorganic nitrogen compounds are converted in one step to N_2 gas as follows:

$$\text{Dry sample} \xrightarrow[550^{\circ}C]{CuO + CaO} N_2\text{-gas}$$

The reaction was carried out on dry material at 550ºC for 6 hours, in a closed nitrogen free atmosphere (discharge) Pyrex-tubes, using copper oxide (CuO) as an oxidizing agent and calcium oxide (CaO) to absorb water and gases like CO_2. When the reaction was completed and the system reached room temperature, the $^{15}N/^{14}N$ ratio was determined by emission spectrometry ^{15}N-analyzer (Model NOI-6PC) following the description of [11].

%Ndff, %Ndfs, and %FUE were calculated according to [11], where Ndff, Ndfs and FUE meant Nitrogen derived from fertilizer, from soil and fertilizer use efficiency, respectively. Nitrogen percent derived from fertilizer (%Ndff) uptake by plant and those remained (%Nrem) in soil after harvest minus 100% N fertilizer rate added give us the percentage of N lost from media by any mechanism.

2.5 Fertilizer N Balance

Above mentioned nitrogen derived from the different sources was estimated using the standard equations described by [11] as following:

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

$$NUE\% = \frac{\text{Ndff kg fed}^{-1}}{\text{Rate of addition kg fed}^{-1}} \times 100$$

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

% N fertilizer losses = % Ndff by plant + % remained in soil – 100% N fertilizer rate

2.6 Statistical Analysis

The obtained data were subjected to ANOVA analysis followed by Duncan's Multiple Range Test (DMRT) for comparison between means according to [12].

3. RESULTS AND DISCUSSION

3.1 Nitrogen Uptake by Tested Crops

Nitrogen uptake by the different tested crops was positively and significantly affected by organic and inorganic fertilizers either applied solely or in combinations (Fig. 1). Values of N uptake by wheat grains as affected by organic sources and mineral fertilizer under sandy soil condition showed that 50% compost C1 + 50% MF treatment induced higher grain-N than those recorded with other treatments. In this regard, application of 50% C1 + 50% MF resulted in 217.8 g plot $^{-1}$ which represent an increase of about 71% over the treatment C1 (100% local compost).

N uptake (g plot^{-1}) by wheat shoot was significantly increased with addition of 50% C1 + 50% MF comparing to other treatments. The effect of both organic and inorganic fertilizer on N uptake by wheat shoot was more pronounced with 50% C1+ 50% MF followed by 50% C2 + 50% MF, where it records 89.7 and 60.4 g N plot^{-1} respectively, while 100% MF recorded 56.5 g N plot^{-1}. Generally, the effect of compost treatments on N uptake by wheat shoot could be arranged as following: (50% C1 + 50% MF) > (50% C2 + 50% MF) > 100% MF > (50% C3 + 50% MF) > 100% C1 > 100%C3 > 100% C2.

On the other hand, 100% C1, 100% C3 and 100% C2 resulted in slight but lower grains-N values as compared with the corresponding achieved by 50% C1 + 50% MF treatment. Regardless of the grains, straw and roots, the overall means of total N uptake indicated (50% CE + 50% MF) treatment as superior over those recorded with all other treatments. A comparison between the 100% organic compost treatment reflected the following ranking: C1 > C3 > C2.

Also the mineral fertilizer plus compost treatments showed higher N uptake by sesame seeds recording 93.15, 85.06 and 78.99 g N plot $^{-1}$ for (50% C1 + 50% MF), (50% C2 + 50% MF) and (50% C3 + 50% MF), respectively than those of 100% compost treatment. Treatment of 100% C3 resulted in the lowest N uptake by seeds (25 g plot^{-1}). Nitrogen uptake by shoots and roots was higher in combined treatments comparing to 100% organic composts or only 100% mineral fertilized plants. Local compost (C1) showed the best results either added solely or in combination with mineral fertilizer. This is true for N uptake by shoots and roots of sesame.

Maize fertilized with sole mineral fertilizer showed positive effect on N uptake by grains, stalks and roots. A reduced N accumulation was observed by the addition of 100% composts. The lowest N uptake by the different plant organs was recorded with plants treaded with 100% C2. Generally, nitrogen uptake by grains was higher than those of stalks or roots. The treatment with (50% C1 + 50% MF) induced highly significant increase in N uptake by grains, stalks and roots as compared to other treatments. Although, individual C3 was superior over individuals C1 and C2, the combined treatments revealed the superiority of local compost (C1) over others. In this regard, the treatments influenced stalks-N could be ranked as following: (50% C1 + 50% MF) > (50% C2 + 50% MF) > 100% MF > (50% C3 + 50% MF) > 100% C1 > 100%C3 >100% C2 but with roots, treatments could be ranked as following: (50% C1 + 50% MF) >100% MF > (50% C3 + 50% MF) > (50% C2 + 50% MF) > 100% C3 > 100% C1 >100% C2. Generally, we can conclude that nitrogen uptake by grain was higher than those of stalks and roots. Application of organic composts especially those combined with mineral fertilizer increased the nitrogen accumulated by different plant parts.

Results indicated that different organic fertilizers may enrich a poor soil such as the sandy studied. Considering the organic-inorganic fertilizers it is recommended to be added to this soil for two benefits, firstly inorganic fertilizers supplied the plants with nutrients required for healthy growth, secondly, organic fertilizers have a major role in microbes' activity which helps in availability of nutrients in soil. Finally, it helps organic matter to easier release of nutrients in available forms through activating the decomposition process of organic matter.

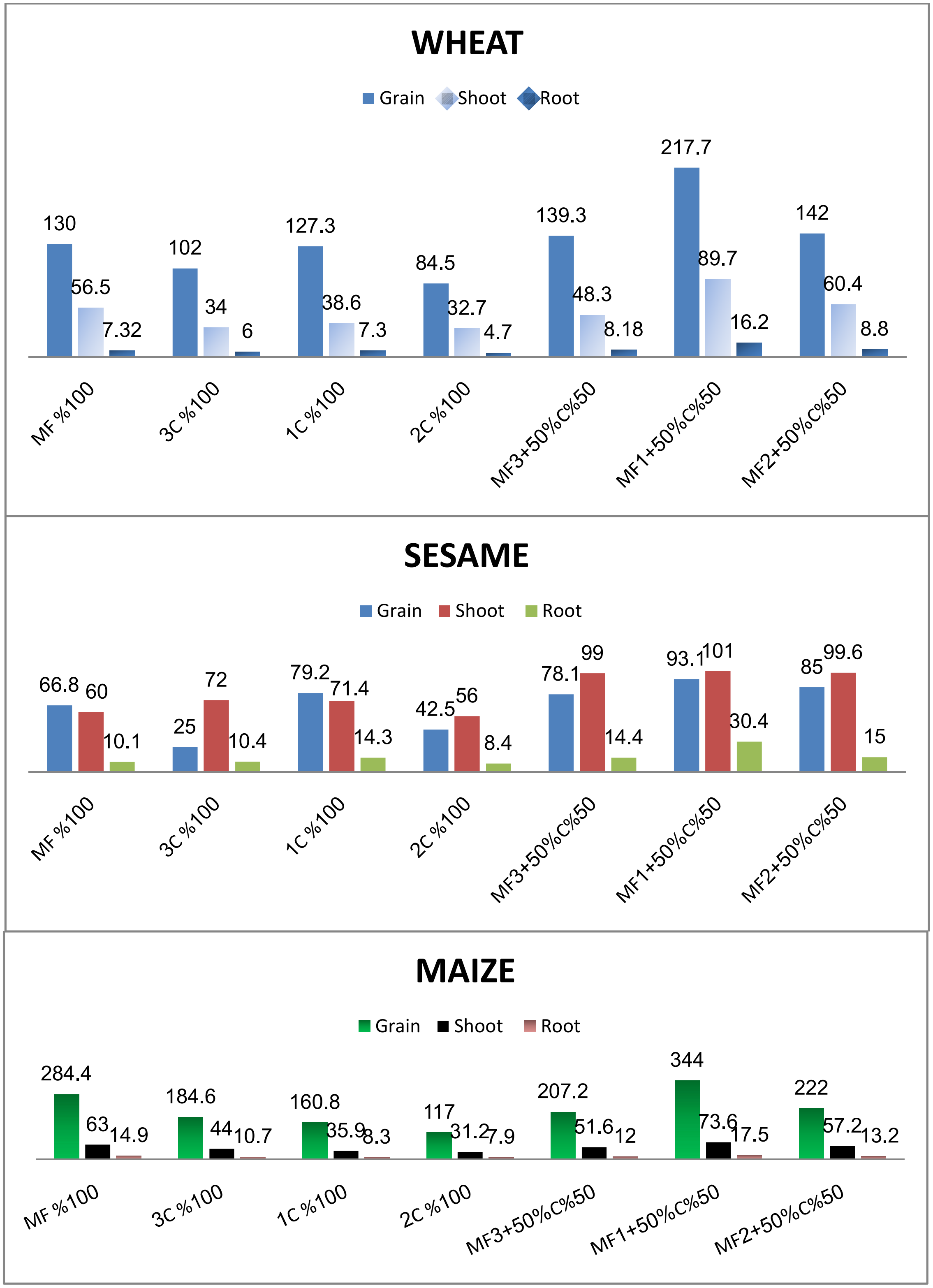


Fig. 1. Effect of inorganic-N fertilizer and organic compost on nitrogen uptake (g plot^{-1}) by different organs of wheat, sesame and maize crops

Mutegi et al. [13] concluded that the differences in nutrient released by the organic-mineral N soil amendments can alter the net rate of nutrient uptake during crop growth. The organic-mineral N soil amendments may assist in synchronization of nutrient release and uptake by the growing crop. Also, they found that sole organics or their integrations with mineral fertilizers can be an alternative to the limited use of fertilizers amongst the small scale farmers in the central highlands.

3.2 Fertilizer-N Balance

Total amount of fertilizer-N applied in the form of ammonium sulfate to different tested crops could be split into bulk remained in soil after harvest, bulk gained by plants and those lost from the media by anyway (Table 3). It seems that fertilizer N remained in soil after maize harvest was higher than those after wheat and sesame. This was true under all fertilization treatments. It is dependable on doses of mineral fertilizer N applied for each crop. Therefore, the quantities of fertilizer N remained in soil as affected by 100% MF (Full dose) were higher than those recorded with other combined treatments. Logically, it could be attributed to low quantities of mineral fertilizer N (half dose) applied in combination with organic compost and in the same time, organic compost may be act as chelating agent and reserve some of the available N into immobilized organic form. Distribution of this proportion along the soil profile of different tested crops will be discussed in the next paragraph.

N balance between soil and wheat plant estimated by [14] indicated that at the harvest of the wheat seedlings, ^{15}N remaining in the soil was equivalent to 30% of chemical fertilizer plus organic manure (CFM) and 18% of chemical fertilizer (CF), respectively. Therefore, large amounts of N moved away from the soil during wheat growing period. N utilization efficiency was 24% (CF) and 30% (CFM). Nitrogen uptake by the whole plant followed the same trend of N remained in soil but to somewhat higher extent. Also, it seems be attributed to the rate of addition for each crop and in the same time affected by combination with organic compost. On the other hand, proportion of nitrogen losses seems to be higher than those remained in soil after wheat crop.

Table 3. Fertilizer-N balance as affected by inorganic and organic fertilizers under wheat, sesame and maize crops

Treatments (T)	Tested crops (C)					
	Wheat		Sesame		Maize	
N-remained						
	%	g plot^{-1}	%	g plot^{-1}	%	g plot^{-1}
100% MF	22.6	121.1	21.1	50.9	20.1	129.2
50%CM+50%MF	17.7	47.4	21.0	25.4	20.1	64.6
50%CE+50%MF	17.7	47.4	20.8	25.1	20.2	64.8
50%CC+50%MF	17.8	47.7	20.7	24.9	29.4	94.4
LSD% T 2.512,	C2.369 , T×C 4.738 / LSD g plot^{-1} T 3.512, C2.369 , T×C 4.738					
Ndff uptake						
	%	g plot^{-1}	%	g plot^{-1}	%	g plot^{-1}
100% MF	46.8	250.8	45.7	110.1	47.7	306.7
50%CM+50%MF	44.5	119.3	41.9	50.7	43.6	139.9
50%CE+50%MF	43.4	116.3	43.2	52.3	42.3	135.8
50%CC+50%MF	42.6	113.9	41.9	50.7	44.6	143.2
LSD% T 2.809,	C2.43 , T×C 4.86 / LSD g plot^{-1} T 2.723, C2.358 , T×C 4.716					
N losses						
	%	g plot^{-1}	%	g plot^{-1}	%	g plot^{-1}
100% MF	30.6	164.0	33.2	80.0	32.2	207.1
50%CM+50%MF	37.8	101.3	37.1	44.9	36.3	116.5
50%CE+50%MF	38.9	104.3	36.0	43.6	37.5	120.4
50%CC+50%MF	39.6	106.1	37.4	45.3	26.0	83.5

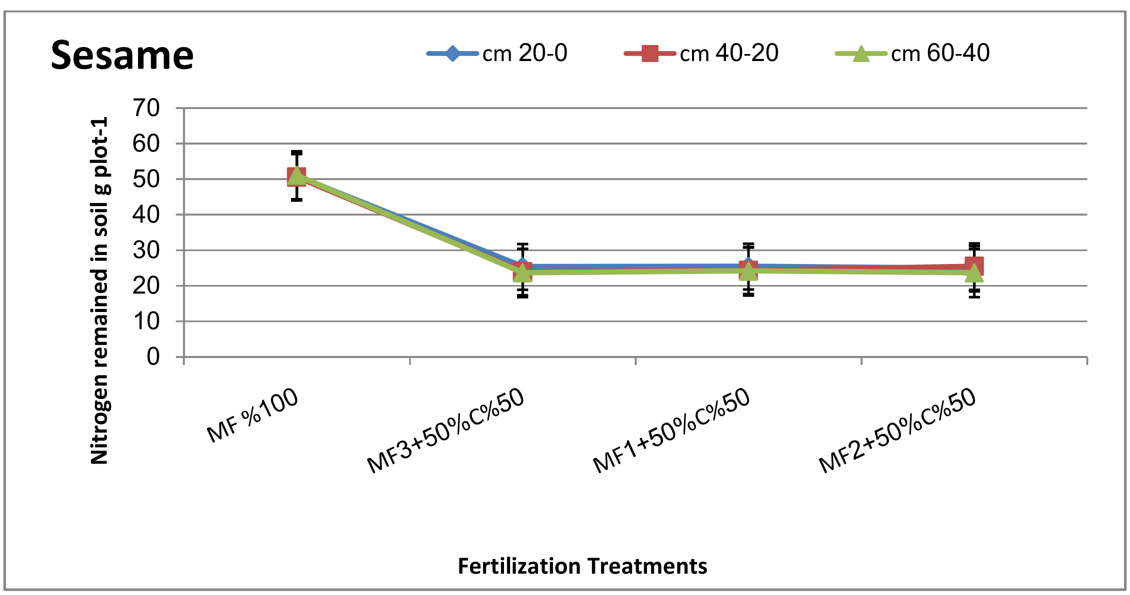
LSD% T 3.512, C3.041, T×C 6.082 / LSD g plot^{-1} T 5.250, C4.54, T×C 9.094

This was true either with fully mineral fertilized plants or those received combination of mineral-organic fertilizers. The proportion of N losses after sesame and maize crops were approximately two fold higher than those remained in soil after harvest. Generally, addition of half rate of mineral fertilizer in combination with organic compost significantly reduced mineral-N losses as compared to fully fertilized one. Also, it could be concluded that N remained in soil, that uptake by plant and those lost from soil media were in relation to the rate of mineral fertilizer added.

3.3 Fertilizer-N in Soil Profile

Fertilizer-N remained in soil and distributed in the soil profile from 0 to 60 cm depth seems to be significantly affected by fertilization treatments (Fig. 2). Under sesame crop, higher N remained in 0-20 cm, 20-40 cm and 40-60 cm were nearly closed to each other. It was higher in case of fully mineral fertilized sesame then sharply declined with combined treatment of different organic compost plus half dose of mineral fertilizer. In this respect, there was no significant difference between organic composts. Also, N remained doesn't significantly varied along the soil depths. Similar effects of combined treatments on N remained were observed with wheat but in case of fully mineral fertilized wheat, high bulk of nitrogen remained was located in 0-20 cm depth and there was no significant difference between 20-40 cm and 40-60 cm depth. A little bit difference was recorded with maize crop whereas N remained localized to some extent in 20-40 cm and 40-60 cm when full dose of mineral fertilizer was applied. Also, the combined treatment of (50% C2+50% MF) showed accumulation of remained-N in the top layer 0-20 cm while the quantities remained in 20-40 cm and 40-60 cm were nearly closed to each other.

In field experiment with rotation of wheat-guar-wheat crops, [15] concluded that after the harvest of the first crop, sewage sludge (SS) compared to all treatments had significantly ($P \leq 0.0001$) increased total nitrogen (TN) in the 0-20 cm depth by 0.04 to 0.07 units and from 0.04 to 0.06 units in the 20-40 cm depth. After the harvest of the second crop, incorporation of wheat residues (with inorganic fertilizer) had significantly increased TN, in the 0-20 cm depth, by 16.67% and by 24.00% (in the 20-40 cm depth) as compared to the inorganic fertilizer alone (RF). After the harvest of the third crop, plots with RF + Crop residue (CR) had consistently maintained the significantly highest topsoil (0 to 20cm depth) TN values as compared to other treatments. The increase in TN due to the application of RF + CR, relevant to SS treatment, was 8.33 units, which is 10.53% after the third crop. Also, continuous incorporation of crop residues has significantly increased the top soil TN as compared to the control treatments. Maximum increased value after the third crops was 78.95%. However, in the lower soil depth (20-40 cm), increased in TN due to the application of RF + CR had been significantly observed after all crops in the cycle.



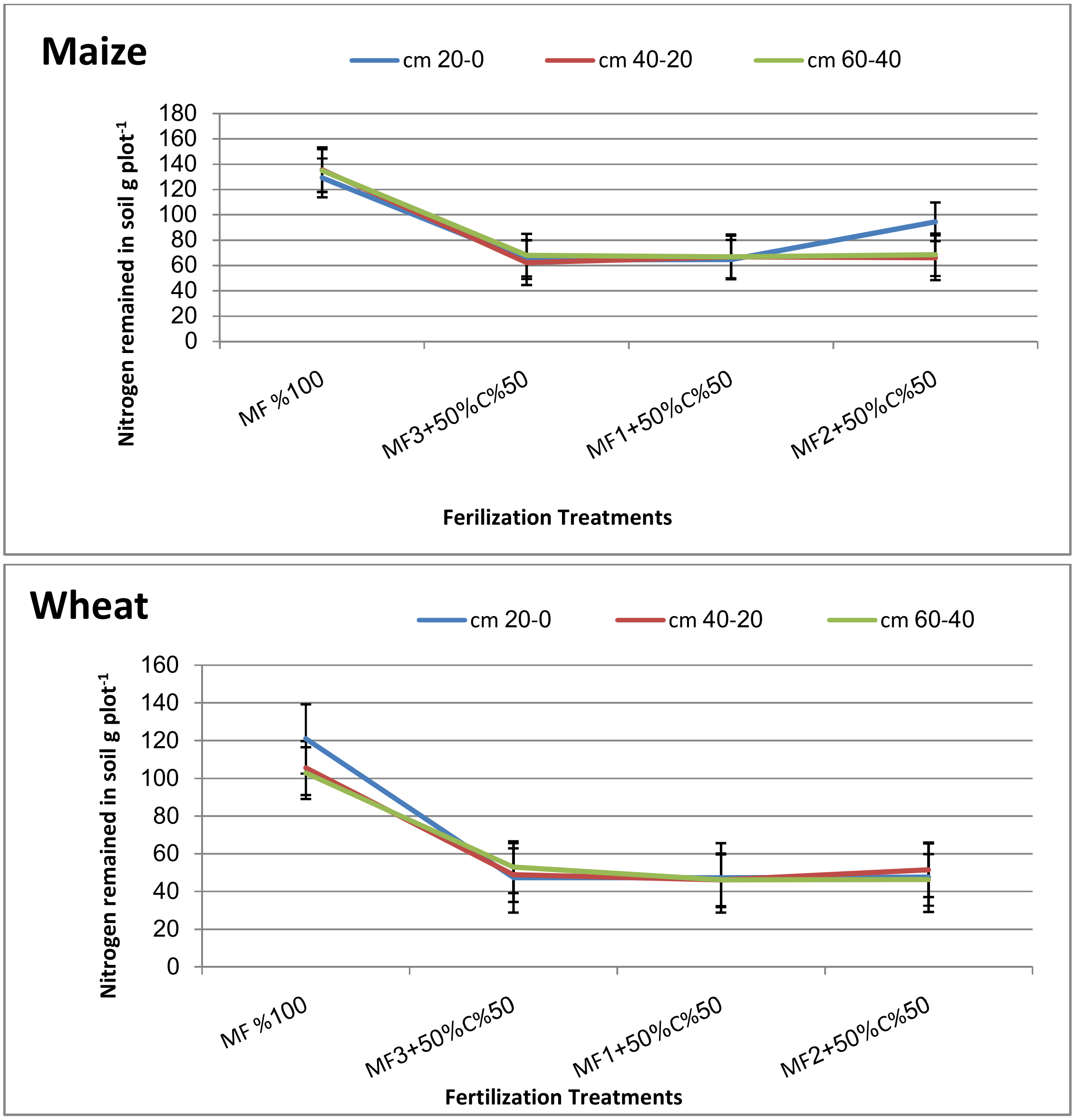


Fig. 2. Nitrogen fertilizer remained and distributed in soil profile after sesame, wheat and maize crops cultivated on virgin sand soil affected by organic and inorganic fertilizer

4. CONCLUSION

In conclusion, nitrogen uptake by the different tested crops was positively and significantly affected by organic and inorganic fertilizers either applied solely or in combinations. In general, we can conclude that nitrogen uptake by grain was higher than those of stalks and roots. Application of organic sources especially combined mixture of compost and mineral fertilizer which increase the nitrogen accumulated by different plant parts.

Distribution of N proportion within the soil profile under different tested crops indicated that addition of half rate of mineral fertilizer in combination with half rate of organic compost significantly reduced mineral-N losses as compared to fully mineral fertilized one. Also, it could be concluded that N remained in soil, uptake by plant and those lost from soil media were in relation to rate of mineral fertilizer added. A little bit difference was recorded with maize crop whereas N remained localized to some extent in 20-40 cm and 40-60 cm when full dose of mineral fertilizer was applied. Also, the combined treatment of 50% C2+50% MF showed accumulation of remained-N in the top layer 0-20 cm while the quantities remained in 20-40 cm and 40-60 cm were nearly closed to each other.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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