Damietta Journal of Agricultural Sciences
http://publication.du.edu.eg/journal/ojs302design/index.php/agr/index
ISSN: 2812-5347(Print)- 2812-5355 (Online)

Optimizing Maize Productivity Through Integrated Nitrogen Fertilization Strategies: Insights from the Stable Nitrogen Isotope (^{15}N) Technique

Soliman M. A. E.[1]; Elshayeb M. M.*[2]; Moursy A. A.[2]

[1] Soil and Water Department, Faculty of Agriculture, Damietta University, Egypt.

[2] Soil and Water Research Department, Nuclear Research Center, Egyptian Atomic Energy Authority, Abou-Zaabal 13759, Egypt

Corresponding author*: love_m2028@yahoo.com

ARTICLE INFO

Keywords:
Bioorganic fertilizers, Isotope dilution, Integrated management, NUE, Plant productivity, Soil fertility.

ABSTRACT

Nitrogen is a vital nutrient for maximizing maize productivity, particularly in arid and semi-arid regions characterized by soil fertility degradation and water scarcity. This study aimed to evaluate the efficacy of integrated nitrogen fertilization strategies, combining chemical, organic, and biofertilizers, to enhance maize performance. Field experiments were conducted using a split-split plot design. Chemical nitrogen was applied as ^{15}N-labeled urea, either alone or in combination with organic amendments of plant origin and mixed forms. Biofertilizers, including Nitrobin, Cerealin, and Phosphorin, were also tested. Results indicated that a 75% urea rate significantly improved grain yield and nitrogen use efficiency (NUE%) compared to a 50% urea rate. While combining organic compost or biofertilizers with urea slightly reduced grain yield, all treatments involving urea, organic amendments, or bacterial inoculants resulted in substantial yield increases over the untreated control. The ^{15}N-labeled data confirmed that urea was the primary nitrogen source for maize, followed by organic compost and biofertilizers. Among the tested combinations, 75% urea with mixed organic compost and Nitrobin outperformed others, demonstrating its potential as an optimal management practice for improving maize productivity under varying fertilization scenarios.

INTRODUCTION

Maize as one of cereal crops utilized globally for staple food consumed by humans, livestock, and dairy animals as well. *Zea mays* (corn) is important because of its components of carbohydrates, fibers, vitamin B, vitamin C, and folic acid (**Ribaut et al. 2009; Cairns et al. 2013**). According to US Department of Agriculture **USDA (2024)**, Egypt produced 7 tons/hectare/year of maize crop in 2024/025 distributed among different governorate (Fig. 1).

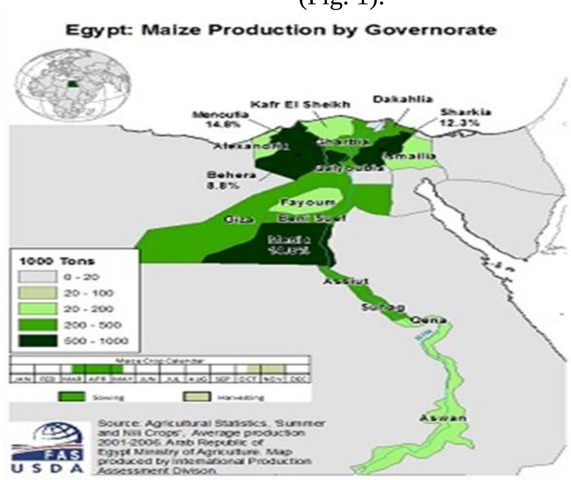


Figure 1. Distribution of maize crop yield ha^{-1} among Egyptian governorates. *Source, USDA 2024.*

Singh et al., (2021 and references therein), referred to the importance of proper management of nutrients to achieve the potential yield in maize production systems because mineral nutrients are the major contributors to increasing crop production (**Khoshgoftarmanesh and Eshghizadeh, 2011**). From the economic and environmental viewpoint, the selection of the most proper approaches to achieve efficient nutrient management systems is very essential. Nitrogen, either in organic or inorganic forms is universally accepted as a key component to high yield in maize production (**Amanullah, 2007**).

For achieving optimum yield and protecting the environment, it should be following the most proper nitrogen fertilization practices. Efficient use of N fertilizers is an effective strategy for both yield and profit (**Ma et al., 2022**). In this respect, crop rotation, no-tillage measures, the use of controlled-release nitrogen fertilizers, the deep application of urea, and the cultivation of NEVs (varieties with higher yields under both N conditions) can be achieved, to overcome the depletion effects of excessive N application, thereby improving crop yield and agro-ecosystem sustainability (**Wu et al., 2011; Zhao et al., 2013; Reetz et al., 2015**).

Considering the role of beneficial microorganisms (PGPRS) it was confirmed its positive impacts on enhancement of plant production **(Loon 2007; Singh 2013; Singh et al. 2020**). These developments of plant growth according to inoculation were attributed to different mechanisms (**Adesemoye and Kloepper 2009**). For example, phosphate is available to the microorganisms in the form of inositol phosphate, phosphotriester, and phosphomonoester (**Dong and Lu 2012; Sharma et al. 2020**). PGPRs solubilize these complex biomolecules into lower molecular weight compounds, such as citric acid and gluconic acid. In case of limited iron in the soil, siderophores are produced by microbial interaction with the host plant.

Recently, many researchers paid attention to the effects of combined straw and manure on cereals productivity (**Duan et al., 2021; Guan et al., 2020**). From the economic and environmental viewpoint, addition of manures reduces chemical fertilizer doses and boost N demand (**Sui et al., 2019**). Soil manuring found to be effective on microbial diversity and activities as well as maintains grain crop yields **(Rusakova and Eskov 2015)**. Under rainfed conditions, **Huai et al., (2024)** found that deep incorporation of straw and manure significantly enhances root growth and spatial distribution of soil water and nutrients, which has great potential for increasing maize yield. Also, they detected notable improvements in the 100-kernel weight and yield (16.1–19.7%) and enhancing water- and nutrient-use efficiencies by 2.5-20.5%. Consequently, biofertilizers allows crops to allocate more energy and resources to above-ground growth and yield enhancement (**Liu et al., 2022; Okada et al., 2017**).

Application of mineral fertilizers in conjunction with organic amendments leads to save remarkable quantities of chemical fertilizers (**Qaswar et al., 2020**; **Gao et al., 2015)**. This strategy found to replace about 20%-30% of chemical fertilizers and in the same time developed yield and availability of soil nitrogen and organic matter formation (**Zhang et al., 2016**).

Therefore, the present research aimed to track and evaluate the impact of nitrogen nutrient from chemical, organic and biological systems on maize crop productivity taking into consideration the economic and environmental dimension.

Materials and Methods

A field experiment was conducted in summer of 2022 at Salamon El-komash Village, Mansoura City, Egypt to track and evaluate the impact of nitrogen management strategies including chemical and bio-organic resources on maize crop productivity. The experimental site has a latitude and longitude 31° 4' 10.092" N 31° 27' 50.76" E, altitude with 15 m above the sea level. Soil samples were collected from 0-30 cm depth before cultivation and exposed to chemical and physical analyses. Some of the physic-chemical properties are presented in Table (1). All physic-chemical analyses were processed according to **Carter and Gregorich (2008)**. Experimental soil was treated with 480 kg super phosphate (15.5% P_2O_5) and 120 kg K_2SO_4 (48 % K_2O_5) at preparing stage.

Table 1. Some of physical and chemical characteristics of the experimental soil.

Characteristic		Value
Sand	**%**	21
Silt		29
Clay		50
Texture		Clay
Available N	**mg kg^{-1}**	50.7
Available P		9.75
Available		305.5
O.M,%		1.45
CEC, cmol kg^{-1}		35.5
EC dSm^{-1}		3.20
pH		8.00

Maize crop variety Triple hybrid 324 provided by Field Crops Research Institute, Ministry of Agriculture and Soil Reclamation (MASR), Egypt was sown at May 25th 2022. Experimental treatments were distributed in split-split-plot statistical design. Urea as chemical fertilizer (46% N) was applied at rates of 75% and 50% from the recommended rate (624 kg ha^{-1} equal to 287 kg N ha^{-1}) in addition to untreated control distributed in the main plots. Plant origin compost and mixed compost were incorporated into the soil of implemented treatments in addition to untreated control. Organic materials were added at rate of 25% and 50% in combination with 75% and 50% urea, respectively and distributed in the sub-plots. Some of chemical constituents of organic sources are presented in table (2). Biofertilizers, i.e. Nitrobin, Cerealin and Phosphorin as commercial names were distributed in the sub-sub-plots Some of the microbial content of these biofertilizers is shown in Table (3). Maize seeds were coated with different microbial inoculants under controlled conditions then cultivated in soil.

Table 2. Some chemical constituents in organic sources.

Characteristic	**Organic compost**	
	Plant origin compost	**Mixed compost**
Weight m^3 kg	740	820
P^H(10:1)	7.30	7.20
EC (10:1) dS m^{-1}	4.05	2.25
N-NH$_4$ (ppm)	293	560
N-NO$_3$ (ppm)	66	85
N (%)	1.01	1.13
O.C (%)	11.98	11.28
O.M (%)	20.66	20.50
P (%)	0.55	0.65
K (%)	0.43	0.27

Microbial inoculums.

Commercial Package	**Constitutes**
Nitrobin	*Azospirillum Lipoferm, Azotopacter Sp*
Cerealin	*Azospirillum Lipoferm, Azotobacter chroococcum, Basillus polymyxa*
Phosphorin	*Bacillus Megatherium*

All treatments were replicated three times and could be summarized as following:

Main factor (N treatments)
- **N$_1$:** 75% of N recommended dose
- **N$_2$:** 50% of N recommended dose
- **N$_3$:** without N fertilization

Sub main factor (organic manure treatments)
- **O$_1$:** Without organic fertilizers
- **O$_2$:** Plant compost
- **O$_2$:** Mixed compost

Sub-sub main factor (Biofertilization treatments)
- **B$_0$:** Un-inoculated control
- **B$_1$:** Nitrobin
- **B$_2$:** Cerealin
- **B$_3$** : Phosphorin

Each experimental treatment occupied an area of 10.5 m^2 (3.5 * 3.0 m) per plot. Urea fertilizer was applied at abovementioned specified rates of ^{15}N-labelled form with 2% ^{15}N atom excess. Different rates of ^{15}N-urea were applied in micro-plot with an area of 1 m^2 placed in the middle of each plot. Data released from such micro-plots were used to determine the different portions of N derived by grains from the different fertilizer sources. The ^{14}N/^{15}N ratio analysis was determined using the emission spectrometer model NOI-6PC Fischer. The portions of nitrogen derived from fertilizer (% Ndff), nitrogen use efficiency (% NUE), N derived from organic (Ndforg) and N derived from air (Ndfa) were estimated using the following Equations according to IAEA TECDOC, (2001):

$$\%Ndff = \frac{\%\,^{15}N\ atom\ excess\ plant}{\%\,^{15}N\ atom\ excess\ fertilizer} \times 100 \quad (1)$$

$$DM\ yield = FW \times \frac{10000}{area\ harvested} \times \frac{SDW}{SFW} \quad (2)$$

$$NY = DM\ yield \times \frac{\%N}{100} \quad (3)$$

$$FNY = NY \times \frac{\%Ndff}{100} \quad (4)$$

$$\%NUE = \frac{FNY}{Rate\ of\ N\ application}$$

$$\%Ndforg = \left(1 - \frac{\%\ 15\text{N a.e. in treated plant}}{\%\ 15\text{N a.e. in untreated plant}}\right) x\ 100 \quad (5)$$

$$\%Ndfa = \left(1 - \frac{\%15\text{N a.e. inoculated plant}}{\%\ 15\text{N a.e. in uninoculated plant}}\right) x\ 100 \quad (6)$$

Biological Yield = sum of plant dry weight / cultivated area (7)

Harvest Index = Grain weight/ Total plant dry weight x 100 (8)

Nitrogen content in plant organs was determined using kejldahl method as described by Estefan et al. (2013).

Statistical analysis

All the obtained data were subjected to an ANOVA analysis of variance for the three studied factors of fertilization and three replicates. The MSTAT-C (version 2.10) computer package was used for analyses. When the ANOVA was significant at a 5% probability level, the least significant difference (LSD) test and Duncan Multiple Range Test (DMRT) were used for mean comparison **(SAS 2002).**

Results

Grain yield and agronomic traits

Grain and biological yields reflected the positive significant effects of individual treatments in including urea fertilizer, organic composts and biofertilizers (Table 3 and Fig. 2). Urea fertilizer applied at 75% and 50% N rates resulted in relative increase of dry grain yield by about 112% and 91%, respectively over the corresponding plants grown without urea (control). In the same time, urea levels induced an increase of biological yield by about 61% and 51% for 75 and 50% N rates, respectively. Similar trend was noticed with harvest index confirming the superiority of 75% N rate.

In case of individual organic additives, data indicated slight increase in grain yield and biological yield of treated plants comparable to the untreated control. Similar trend was observed with harvest index. It is worthy to mention that significant differences in grain yield and biological yield between different organic sources were not sufficiently clear. Variation in grain and biological yields as well as harvest index as affected by different bacterial inoculums was not clear cut.

Table 3. Effect of fertilization strategies on grain yield and agronomic traits of maize crop

Treatments	Grain yield (ton ha^{-1})	Dry Grain yield (ton ha^{-1})	Biological yield ton ha^{-1}	Harvest index %
Urea rates				
0%	3.30c	2.14d	15.07c	14.20c
50%	6.31b	4.10b	20.35b	20.14b
75%	7.01a	4.55a	21.98a	20.70a
Organic additives				
0	5.19c	3.37b	18.51c	18.20c
Plant	5.60b	3.64a	19.14b	19.01b
Mixture	5.82a	3.78a	19.74a	19.14a
Microbial inoculums				
0	5.40c	3.51b	18.85c	18.62a
Nitrobin	5.61a	3.64a	19.11a	19.04a
Cerealin	5.54b	3.60a	19.20ab	18.75a
Phosphorin	5.47c	3.55b	18.99b	18.69a

Mean values in the same column followed by the same letter are not significantly different at $p \leq 0.05$

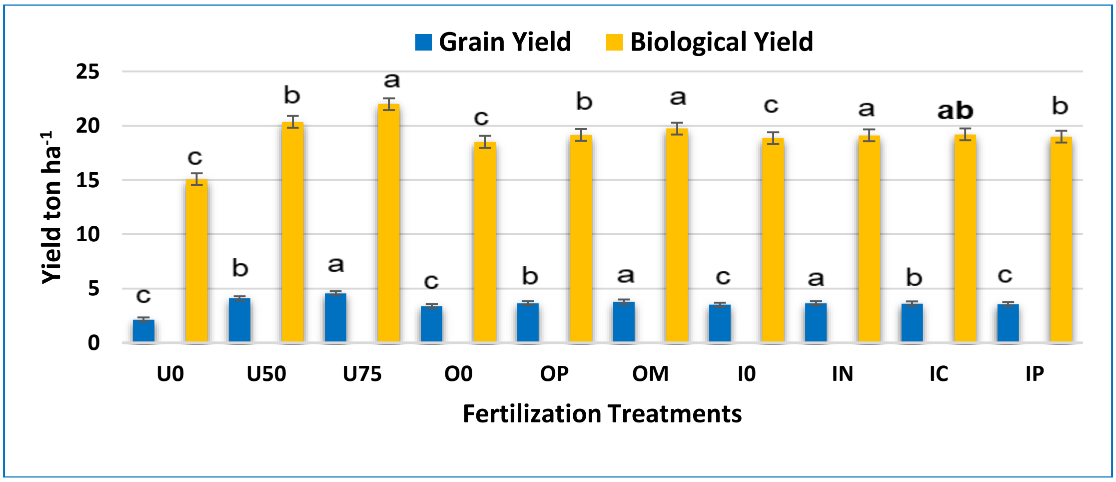


Figure 2. Main and sub-main factors affecting grain and biological yields of maize crop

Yield components such as number of seeds per cob, cob length and diameter and weight of 1000 seeds were significantly enhanced by individual urea rates, organic sources and microbial inoculants as compared to the untreated controls (Table 4 and Fig. 3). All agronomic traits were higher in case of 75% urea rate, mixed compost and Nitrobin inoculums than other treatments. For example, number of seeds per cob of plants treated with 75% urea rate was relatively increased by about 9% and 54% over 50% rate and the untreated control, respectively. Similar trend was noticed with weight of 100 seeds.

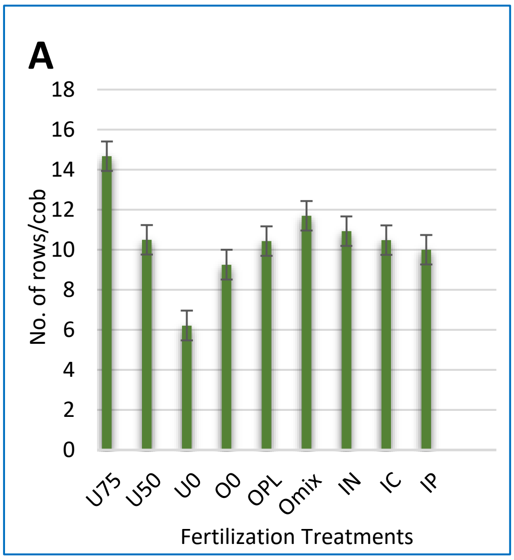
Considering the interaction effect of different fertilization treatments, it was clear that the best grain yield (Table 5A and Fig. 4A), was achieved by application of mixed compost in combination with 75% urea rate and plants inoculated with Nitrobin followed by those recorded under 50% urea rate then those of the unfertilized control. Similar trend, but to somewhat

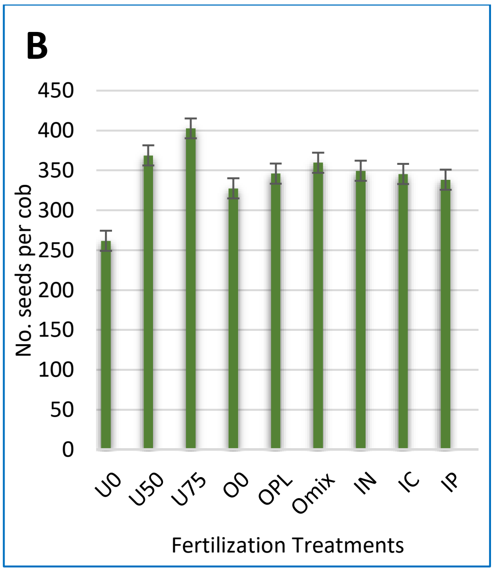
lower extent, was observed with Cerealin and Phosphorin inoculums. Similar trends were detected for biological yield (Table 3B and Fig. 4B) and harvest index (Table 3C). All measurements as affected by bacterial inoculation were, to some extent, higher than those recorded for the un-inoculated control treatments.

Table 4. Effect of fertilization strategies on some yield components of maize crop**.**

Treatments	No. of rows/cob	No. seeds per cob	Cob length (cm)	Cob diameter (cm)	Weight of 1000 seed (g)
Urea rates					
0%	6.22c	261.70c	15.29c	2.12c	306.76c
50%	10.52b	368.74b	21.83b	2.68b	362.07b
75%	14.67a	402.70a	25.32a	2.95a	373.76a
Organic additives					
0	9.26c	327.44c	19.26c	2.47c	341.74c
Plant	10.44b	345.96b	21.09b	2.60b	348.17b
Mix	11.70a	359.74a	22.09a	2.69a	352.69a
Microbial inoculums					
0	9.73c	309.23c	17.55c	2.31c	293.35c
Nitrobin	10.93a	349.41a	21.14a	2.62a	349.23a
Cerealin	10.48ab	345.44a	20.82b	2.59a	347.83ab
Phosphorin	10.00b	338.30b	20.48b	2.55b	345.54b

Mean values in the same column followed by the same letter are not significantly different at $p \leq 0.05$





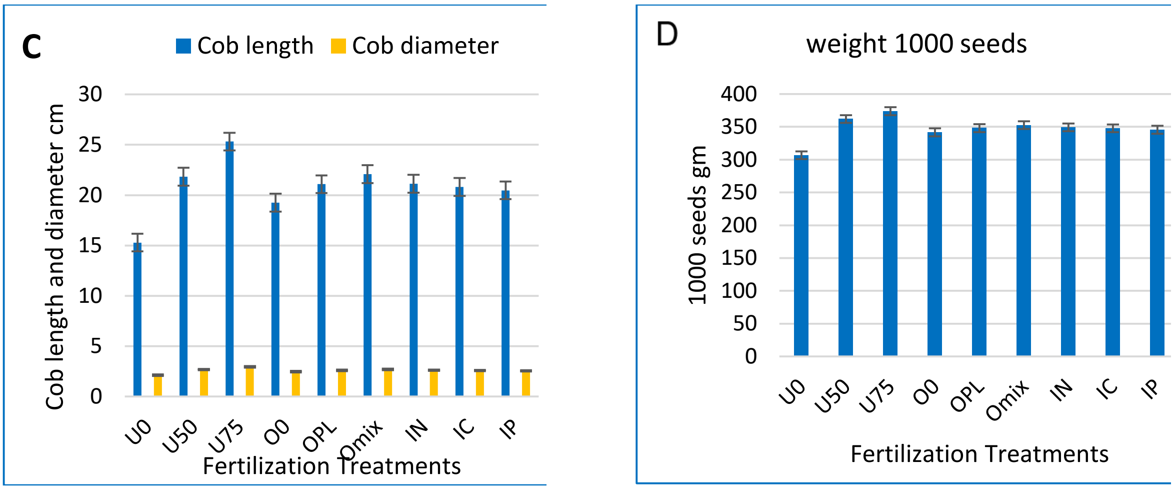


Figure 3. Effect of fertilization strategies on **A)** no of row per cob, **B)** no of seeds per cob, **C)** cob length and diameter and **D)** weight of 1000 seeds.

Table 5. Interaction effects of inorganic, organic and biofertilizers on grain yield, biological yield and harvest index of maize crop.

5A. Grain Yield ton ha^{-1}

Urea rates	Organic compost	Biofertilizers			
		Un-inoc	Nitrobin	Cerealin	Phosphorin
0	None	1.65^{d}	1.91^{d}	1.89^{d}	1.85^{d}
	Plant compost	2.20^{cd}	2.24^{c}	2.21^{c}	2.19c
	Mixed compost	2.24^{cd}	**2.34^{c}**	2.32^{c}	2.29c
50	None	2.86^{c}	3.91^{b}	3.87^{b}	3.71^{b}
	Plant compost	3.25^{b}	4.18^{a}	4.13^{ab}	4.06^{b}
	Mixed compost	3.47^{b}	**4.34**	4.33^{ab}	4.32^{ab}
75	None	4.11^{a}	4.48^{a}	4.37^{ab}	4.34^{ab}
	Plant compost	4.37^{a}	4.58^{a}	4.57^{a}	4.55^{a}
	Mixed compost	4.38^{a}	**4.76^{a}**	4.64^{a}	4.64^{a}

5B. Biological Yield ton ha^{-1}

Urea rates	Organic compost	Biofertilizers			
		Un-inoc	Nitrobin	Cerealin	Phosphorin
0	None	14.05^{c}	14.35^{d}	14.26^{de}	14.53^{d}
	Plant compost	14.52^{c}	15.07^{c}	14.85^{de}	15.35^{c}
	Mixed compost	15.20^{c}	**15.79^{c}**	15.48^{d}	15.40^{c}
50	None	18.76^{b}	19.71^{bc}	19.46^{bc}	19.12^{bc}
	Plant compost	19.66^{b}	20.59^{b}	20.30^{bc}	20.02^{b}
	Mixed compost	20.78^{b}	**21.38^{b}**	21.32^{b}	21.23^{a}
75	None	21.00^{a}	21.69^{b}	21.54^{b}	21.43^{a}
	Plant compost	21.49^{a}	22.11^{ab}	22.02^{a}	21.97^{a}
	Mixed compost	21.92^{a}	**22.46^{a}**	22.27^{a}	22.27^{a}

5C. Harvest Index %

Urea rates	Organic compost	Biofertilizers			
		Un-inoc	Nitrobin	Cerealin	Phosphorin
0	None	11.74^{d}	13.31^{c}	13.25^{d}	12.73^{d}
	Plant compost	15.15^{bc}	14.86^{b}	14.88^{c}	14.26^{c}
	Mixed compost	14.74^{bc}	**14.81^{b}**	14.98^{c}	14.87^{c}
50	None	15.25^{bc}	19.83^{ab}	19.88^{b}	19.40^{b}
	Plant compost	16.53^{b}	20.30^{ab}	20.34^{a}	20.27^{a}
	Mixed compost	16.70^{b}	**20.29^{ab}**	20.30^{a}	20.34^{a}
75	None	19.57^{ab}	20.65^{a}	20.28^{a}	20.25^{a}
	Plant compost	20.34^{a}	20.71^{a}	20.75^{a}	20.71^{a}
	Mixed compost	19.98^{a}	**21.19^{a}**	20.83^{a}	20.83^{a}

Mean values in the same column followed by the same letter are not significantly different at $p \leq 0.05$

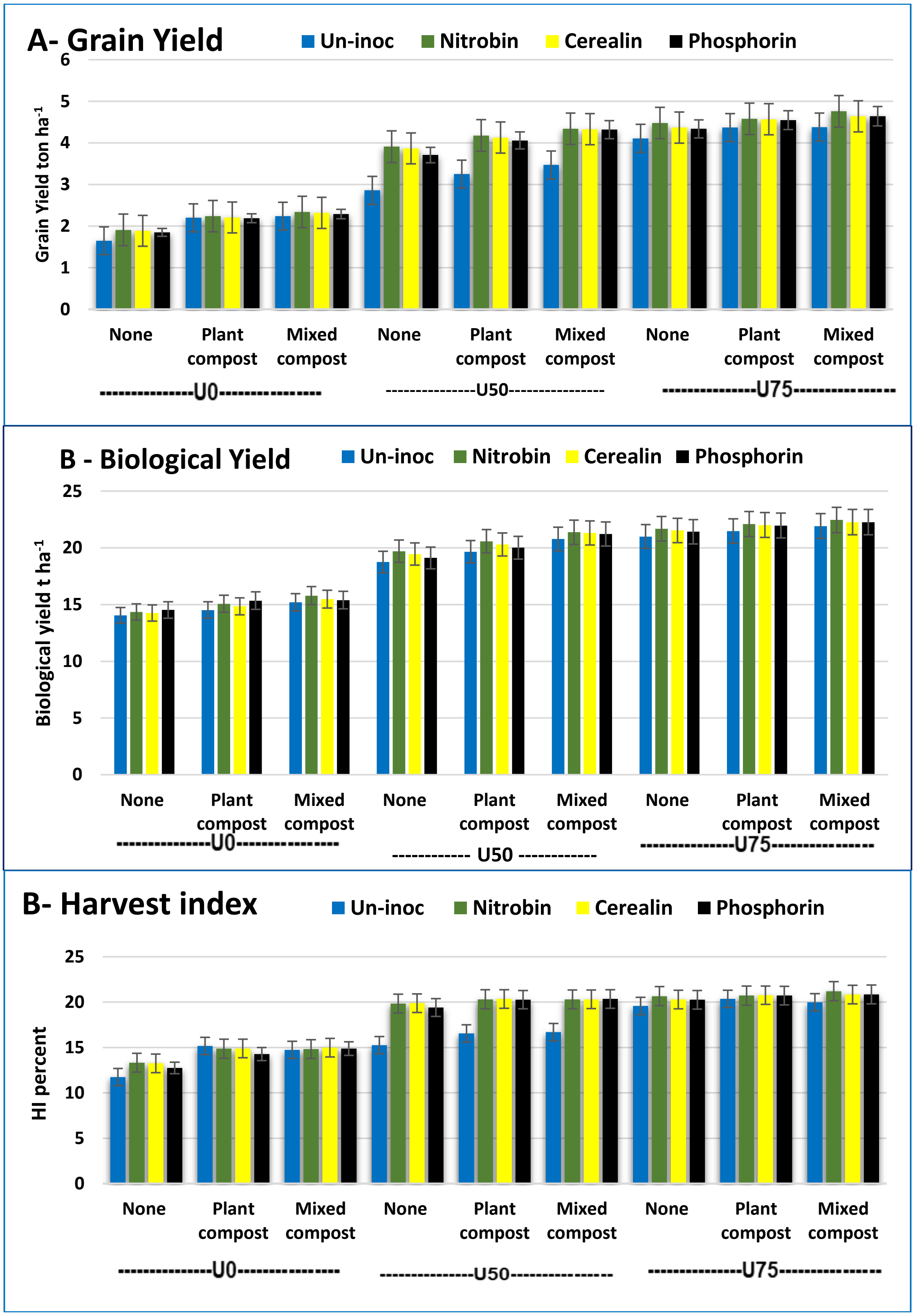


Figure 4. Effect of inorganic, organic and biofertilizers on **A)** grain yield and **B)** biological yield (ton ha^{-1}) of maize crop.

Nitrogen applied in different forms either individually or in combinations have a crucial impact on maize growth traits and biological yield and consequently on N portions derived from examined sources to the plant. Application of ^{15}N tracer technique has the ability to distinguish between N derived from chemical fertilizer, organic sources and those derived from air via biological nitrogen fixation process. In the next section we will discuss the contribution of different N portions in improving maize nutrition and productivity. It seems that nitrogen uptake by grains was significantly varied according to fertilization strategies (Fig. 5). Nitrogen uptake by grains recorded the highest value with application of 75% urea fertilizer while the lowest value recorded with combined treatment of Phosphorin plus 50% urea. Among the combined fertilization treatments, mixed organic compost plus 50% urea resulted in the highest N uptake by grains. Comparison held between the highest and lowest N uptake values revealed that urea added at 75% rate achieved a relative increase in N uptake by about 87% over the combined treatment of Phosphorin plus 50% urea. On the other hand, reduced urea rate (50%) resulted in reduction of N uptake by grains by about 33.7% lower than those recorded with 75% urea rate.

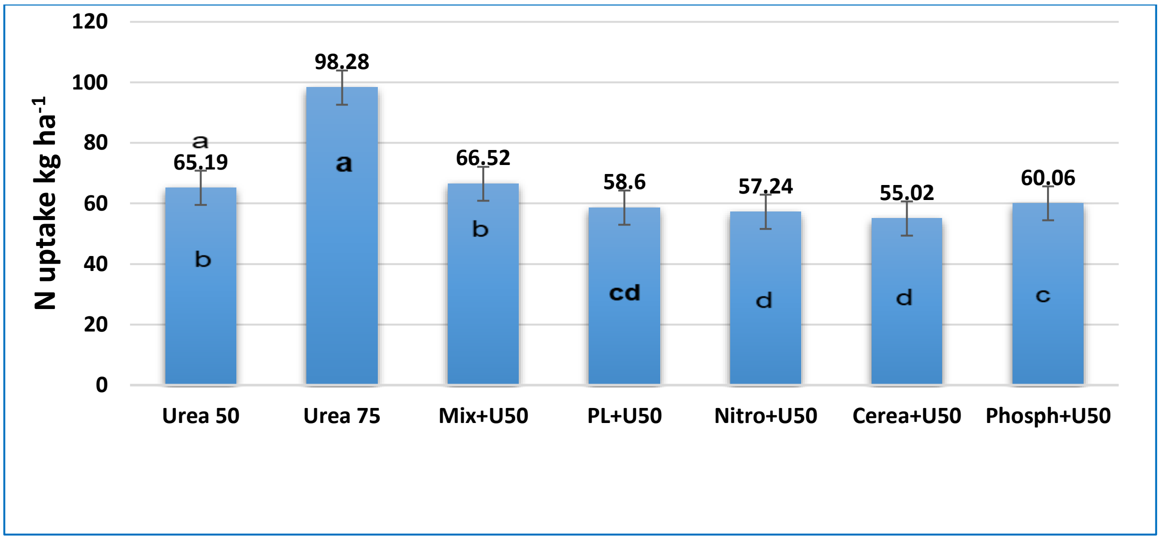


Figure 5. Nitrogen uptake by maize grains as affected by different fertilization treatments.

Both plant residue compost and mixed compost were nearly closed to each other and to some extent substitute a reasonable amount of urea chemical fertilizer (50%) which play an important role in nutrition of maize crop in addition to its effects on fertility and structure of cultivated soil. All the three biofertilizers were nearly closed to each other.

Portions of nitrogen derived from urea, organic and bio-fertilizers – Ndff, Ndforg, Ndfa and NUE%

Portions of nitrogen derived from urea, organic composts and biofertilizers by maize grains were presented in Table (6). Application of urea at rate of 75% individually contributed by 43.9 kg of nitrogen uptake by grains. This amount was decreased by about 50% when urea rate reduced to 50%. Nearly closed values of Ndff by grains were noticed with combined urea (50%) plus plant residue and mixed composts recording 26.0, 28.5 and 25.1 kg N ha^{-1} for urea, urea + plant residue and urea + mixed compost, respectively. The lowest Ndff values were recorded with combined treatments of urea plus the examined three biofertilizers and nearly closed to each other.

Data doesn't reflect significant difference between the two examined organic composts in compensating reasonable amount of nitrogen released from it. It means that both of them could be used in combination with half doses of recommended chemical fertilizer as most cheap and ecofriendly nutritional sources. Concerning the impact of biofertilizers, data indicated that the highest value of Ndfa was induced by Phosphorin inoculum followed by Cerealin then Nitrobin which resulted in the lowest value among them. It is obvious that the contribution of bio-effectors in nitrogen content in grains was nearly closed to those provided by organic sources but both of them still lower than those derived from the full urea rate.

Table 6. Impact of fertilization management practices on N derived from urea, organic and biofertilizers uptake by grains of maize crop.

Fertilization	Portions of N derived from different sources						
	Ndff		NUE%	Ndforg		Ndfa	
	%	kg ha^{-1}		%	kg ha^{-1}	%	kg ha^{-1}
50% Urea	55.0	35.9^{b}	53.6	-	-	-	-
75% Urea	60.4	59.4^{a}	44.3	-	-	-	-
50 Mix Compost + 50 Urea	46.4	30.9^{c}	46.1	19.6	14.6^{b}	-	-
50 Plant Compost + 50 Urea	45.4	26.6^{d}	39.7	21.3	14.2^{b}	-	-
Cerealin + 50 Urea	49.7	23.9^{d}	35.7	-	-	27.5	14.7^{ab}
Phosphorin +50 Urea	41.8	21.9^{d}	32.7	-	-	31.0	16.3^{a}
Nitrobin + 50 Urea	39.8	29.8^{c}	44.5	-	-	13.8	7.6^{d}

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

Efficient use of Urea-N (Fig. 6), tended to increase when half dose was combined with plant residue compost and in the same time the half dose was more efficiently used by grains comparing to the 75% dose. Similar trend was noticed with application of urea plus mixed compost. Urea combined with the different biofertilizers achieved moderate NUE% comparable to other treatments.

Comparison held between different plant organs revealed that NUE by grain was significantly higher than those of shoots and roots in case of plants treated with 50U, mix comp+50 U, PL+50U, Nitrobin+50U and Cerealin+50U (**Fig. 6**). Contrary, nitrogen was more efficiently use by shoots than grains and roots of plants fertilized with solely 75U and those treated with phosphorin+50U. the lowest NUE percentages were indicated with root system.

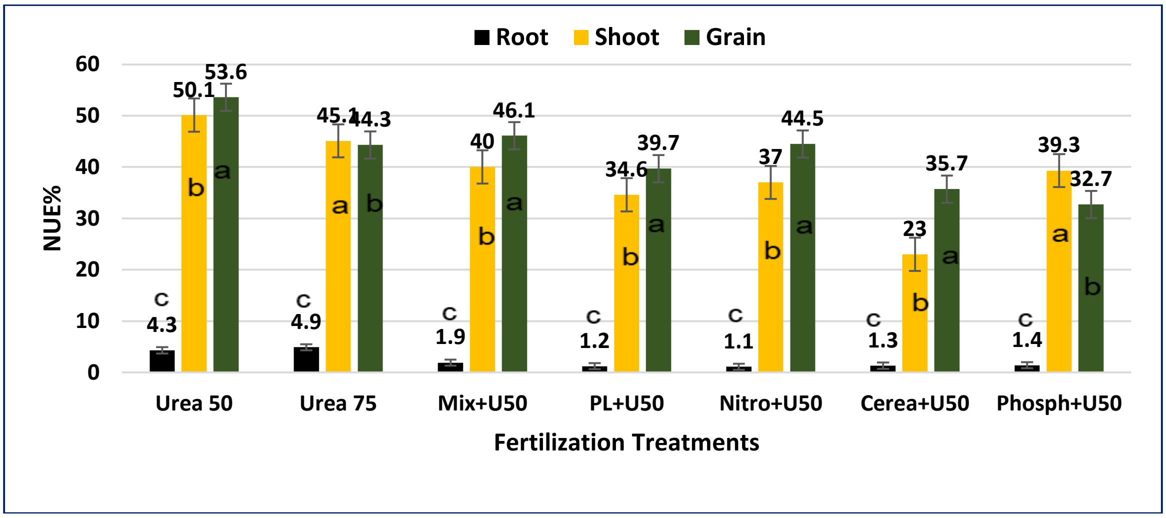


Figure 6. Efficiency of N used by rootshoot and grain of maize crop grown on fertile silty clay soil.

Discussion

Grain yield and agronomic traits

This study demonstrates that incorporation of organic ameliorates either individually or in combination with chemical fertilizer and bio-effectors can significantly positively alter root growth patterns which contribute to improve the utilization of water and nutrients in deeper soil layers (**Huai et al., 2024**). This modification in soil media reflected promotion of plant growth and enabling maize to adopt deeper root growth strategies and thereby enhancing overall growth performance (**Gong et al., 2020; Yin et al., 2021**).

Present findings indicated that cob length and diameter, seeds number per cob and weight of 1000 seeds is closely related to enhancement of maize growth promotion due to combined treatments of composts and bacterial inoculants. Some researchers demonstrated that compost incorporation into the soil have stimulation effects on root architecture that helps the plant to be resilient during critical growth stages such as tasseling and grain filling (**Dhayal et al., 2023; Cheng et al., 2020**). This strategy enhances crop resilience and overall yield (**Alhaj Hamoud et al., 2019; Gong et al., 2020; Yin et al., 2021**). Therefore, **Huai et al., (2024)** recommended deep incorporation of organic materials that has significant advantages in improving crop growth efficiency and yield, instead of shallow incorporation which leads to high root turnover and metabolic costs, adversely affecting long-term crop health and growth. On line with the present results, **Ma et al., (2022)** reported gradual decrements in grain yield attributed to the reduction of nitrogen rate. On the other hand, the grain number per ear and thousand-kernel weight were significantly decreased under low nitrogen conditions, the grain number per ear in nitrogen efficient varieties (NEVs) and nitrogen inefficient varieties (NIVs) were reduced by about 8.63-15.51% and 19.67-20.50%, respectively. The grain number per ear were significantly higher for NEVs than for NIVs under both N conditions. Compared with high nitrogen conditions, the thousand-kernel weight in NEVs and NIVs were reduced by about 5.97-11.59% and 9.44-11.62%, respectively. Recently, **Abdul Basir et al. (2025)** confirmed the positive significant effects of compost plus mineral NPK (50: 50) on improving wheat growth and yield quality under calcareous soil conditions.

^{15}N Tracer Technique

Nitrogen utilization from different sources

Enhancement of maize growth and grain yield was more dependent on nitrogen derived from urea at both application levels followed by nitrogen released from organic manures. Small amounts of nitrogen content in grains was derived from air and seems to be logic whereas the all inoculums contain associative and free-living microorganisms where their capacity in fixing nitrogen from air is low but their indirect mechanisms in excreting phytohormons, organic acids and growth promoting regulators and phosphatases enzymes responsible for solubilizing sparingly soluble P in soil took place. Much more researchers covered this area. For example, **Yadav et al., (2017)**, attributed the development of maize growth and yield to favorable nutritional status of soil in addition to the effect of FYM on microbial activity and root proliferation in soil that helps in P solubilization in addition to other nutrients.

There is great genetic variability in both nitrogen uptake efficiency and nitrogen physiological use efficiency in maize. In many cases, maize varieties that perform best under high nitrogen fertilizer inputs do not necessarily perform well when nitrogen supplies are reduced (**Gallais and Coque, 2005**), which is related to nitrogen management strategies and environmental factors. Nitrogen uptake and nitrogen utilization efficiency of different maize varieties tend to be opposite at different nitrogen supply levels (**Fixen et al., 2015**). Recent observations after **Abdul Basir et al. (2025)** indicated that nitrogen was more efficiently used by wheat plants treated with 50% compost + 50% NPK recording 36% increases over the untreated plants.

Conclusion

Balanced and integrated fertilization strategies are among the pillars and foundations of improving plant production, taking into account the economic and environmental dimensions represented in reducing the cost of production and reducing total dependence on chemical fertilizers. Hence, the current research in our hands was directed towards recycling and using organic compost in addition to biofertilizers that include microbes associated with the roots of cereal plants and have the ability to fix atmospheric nitrogen freely in the root zone of plants, in addition to secreting some phytohormones that help improve the plant's absorption of nutrients. In this respect, application of ^{15}N tracer technique gave us the chance to explore the accurate amounts of nitrogen derived by grains of maize from either chemical urea, organic composts and air via inoculum-plant association. It was confirmed that maize crop depends to high extent on N derived from urea fertilizer. This portion of N was more efficiently used by grain when urea applied at high rate comparable to the reduced rate. Both organic composts and biofertilizers compensated a reasonable amounts of N derived to grains which gave us the ability to recommend these biological bio-effectors as tools that help stimulate the plant to absorb soil nutrients, in addition to facilitating the sparingly soluble forms of them, as in the case of phosphorus. From the released data we can recommend a half dose of chemical urea in combination with considerable quantities of organic manures as well as biofertilizers that provide maize crop with N released from associative microbes in the plant rhizosphere. Integrated nutrient management including chemical and bioorganic forms could be accepted as an ecofriendly economic approach.

Acknowledgement

Authors wishes to express their appreciation to Prof Dr. YGM Galal, Soil and Water Research Department, Egyptian Atomic Energy Authority for his reviewing and revision of the article.

References

Abdul Basir, Iqbal S., Adnan M., Khan M. A., Lal R., Fahad S., Saeed B., Ahmad M., Al-Ashkar I., Toprak Ç., Erden Z. and El Sabagh A. (2025) Integration of compost with mineral NPK fertilizers for improving wheat yield and soil health. Pak. J. Bot., 57(3): 1-9, DOI: http://dx.doi.org/10.30848/PJB2025-3(19)

Adesemoye AO, Kloepper JW (2009) Plant-microbes interactions in enhanced fertilizer-use efficiency. Appl Microbiol Biotechnol 85(1):1-12

Alhaj Hamoud, Y.; Shaghaleh, H.; Sheteiwy, M.; Guo, X.; Elshaikh, N.A.; Ullah Khan, N.; Oumarou, A.; Rahim, S.F. (2019) Impact of Alternative Wetting and Soil Drying and Soil Clay Content on the Morphological and Physiological Traits of Rice Roots and Their Relationships to Yield and Nutrient Use-Efficiency. Agric. Water Manag., 223, 105706. [CrossRef]

Amanullah M. (2007) Partitioning of dry matter and grain yield potential in maize (*Zea mays* L.) as influenced by plant density, rate and timing of nitrogen application. International Journal of Sustainable Crop Production;2(5):1-7.

Cairns JE, Crossa J, Zaidi P, Grudloyma P, Sanchez C, Araus JL, Thaitad S, Makumbi D, Magorokosho C, Bänziger M (2013) Identification of drought, heat, and combined drought and heat tolerant donors in maize. Crop Sci 53(4):1335-1346

Carter, M.R., Gregorich, E.G., (2007) Soil Sampling and Methods of Analysis, 2nd ed. CRC Press, Taylor & Francis Group, 6000 Broken Sound Parkway NW, Suite 300, Boca Raton, pp. 1-1262. https://doi.org/10.1201/9781420005271.

Cheng, Y.; Wang, H.-Q.; Liu, P.; Dong, S.-T.; Zhang, J.-W.; Zhao, B.; Ren, B.-Z. (2020) Nitrogen Placement at Sowing Affects Root Growth, Grain Yield Formation, N Use Efficiency in Maize. Plant Soil, 457, 355-373. [CrossRef]

Dhayal, D.; Lal, K.; Khanna, M.; Sudhishri, S.; Brar, A.S.; Sindhu, V.K.; Singh, M.; Bhattacharyya, R.; Rajath, E.; Rosin, K.G.; Chakraborty D. (2023) Performance of Surface and Subsurface Drip Fertigated Wheat-Moongbean-Maize Cropping System under Different Irrigation Schedules and Nutrient Doses. Agric. Water Manag., 284, **108338. [CrossRef]**

Dong H, Lu A (2012) Mineral–microbe interactions and implications for remediation. Elements 8(2):95-100

Duan, Y.; Zhang, H.; Han, M.; Hong, A.; Li, Y.; Sun, G.; Gao, P.; Sun, Y.; Ran, W.; Shen, J.; Shen, X.; Wu C. and Ji M. (2021) Changes in Dominant Weeds of Wheat in a Rice-Wheat Rotation System as Affected by Composted Manure and Straw Amendments. Weed Sci., 69, 219-229. [CrossRef]

Estefan, G., Sommer, R., Ryan, J., (2013) Methods of Soil, Plant, and Water Analysis: A Manual for the West Asia and North Africa Region. International Center for Agricultural Research in the Dry Areas (ICARDA), Beirut, Lebanon.

Fixen, P., Brentrup, F., Bruulsema, T., Garcia, F., Norton, R., and Zingore, S. (2015) Nutrient/fertilizer use efficiency: Measurement. Curr. Situat. Trends 33, 8-38.

Gallais, A. & Coque, M. (2005) Genetic variation and selection for nitrogen use efficiency in maize: A synthesis. Maydica 50(3), 531-547.

Gong, X.; Dang, K.; Lv, S.; Zhao, G.; Tian, L.; Luo, Y.; Feng, B. (2020) Interspecific Root Interactions and Water-Use Efficiency of Intercropped Proso Millet and Mung Bean. Eur. J. Agron., 115, 126034. [CrossRef]

Guan, X.-K.; Wei, L.; Turner, N.C.; Ma, S.-C.; Yang, M.-D.; Wang, T.-C. (2020) Improved Straw Management Practices Promote in Situ Straw Decomposition and Nutrient Release, and Increase Crop Production. J. Clean. Prod., 250, 119514. [CrossRef]

Huai, S.; Wang, S.; Yu, W.; Zhang, Q.; Wu, H.; Xing, T.; Jin, Y.; Colinet, G.; Lu, C. (2024) Short-Term Effects of Incorporation Depth of Straw Combined with Manure During the Fallow Season on Maize Production, Water Efficiency, and Nutrient Utilization in Rainfed Regions. Agronomy, 14, 2504. https://doi.org/10.3390/agronomy14112504

IAEA, (2001). A Manual, Use of Isotope and Radiation Methods in Soil and Water Management and Crop Nutrition, Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, Training Course Series No. 14. IAEA, A-1400 Vienna, Austria.

Khoshgoftarmanesh AH, Eshghizadeh HR. (2011) Yield Response of Corn to Single and Combined Application of Cattle Manure and Urea. Communications in Soil Science and Plant Analysis; 42:1200-1208.

Liu, J.; Liu, J.; Wang, J.; Wang, H.; Zuo, J.; Hu, D. (2022) Fruit Yield and Properties of *Camellia oleifera* Abel Can Be Enhanced via Fine Roots Promotion under Mulch. Arch. Agron. Soil Sci., 68, 1175-1191. [CrossRef]

Ma B., Wang J., Han Y., Zhou C., Xu T., Qu Z., Wang L., Ma B., Yuan M., Wang L., Ding X. & Qian C. (2022) The response of grain yield and ear differentiation related traits to nitrogen levels in maize varieties with different nitrogen efficiency. **Scientific Reports** (2022) 12:14620 https://doi.org/10.1038/s41598-022-18835-z

Okada, K.; Aiba, S.; Kitayama, K. (2017) Influence of Temperature and Soil Nitrogen and Phosphorus Availabilities on Fine-Root Productivity in Tropical Rainforests on Mount Kinabalu, Borneo. Ecol. Res., 32, 145-156. [CrossRef]

Reetz, H. F., Heffer, P. & Bruulsema, T. W. (2015) 4R nutrient stewardship: A global framework for sustainable fertilizer management. In Managing Water and Fertilizer for Sustainable Agricultural Intensification (eds Drechsel, P. et al.) 65 (International Fertilizer Industry Association (IFA), International Water Management Institute (IWMI), International Plant Nutrition Institute (IPNI), and International Potash Institute (IPI).

Ribaut J-M, Betran J, Monneveux P, Setter T (2009) Drought tolerance in maize. Handbook of maize: its biology. Springer, pp 311-344

Rusakova, I.V.; Eskov, A.I. (2015) Effect of Poultry Manure in Combination with Straw on the Biological Properties of Soddy-Podzolic Soil and the Yielding Capacity of Grain Crops. Russ. Agricult. Sci., 41, 357-361. [CrossRef]

SAS (2002) The SAS System for Windows. Release 9. 0. SAS Inst. Inc., Cary, NC.

Sharma V, Salwan R, Tawfeeq L (2020) Molecular aspects of plant beneficial microbes in agriculture. Academic Press

Singh DP, Singh V, Gupta VK, Shukla R, Prabha R, Sarma BK, Patel JS (2020) Microbial inoculation in rice regulates antioxidative reactions and defense related genes to mitigate drought stress. Sci Rep 10(1):1-17

Singh JS (2013) Plant growth promoting rhizobacteria. Resonance 18(3):275–281

Sui, X.; Guo, H.; Li, Z.; Wang, M.; Wang, Y.; Zhang, X. (2019) Effect of Corn Straw Manure as Dairy Manure on Productivity and Profitability of Wheat at Huang-Huai-Hai Plain. J. Environ. Biol., 40, 441–447. [CrossRef]

U.S. Department of Agriculture USDA (2024). Country Report, Egypt Production. https://ipad.fas.usda.gov/countrysummary/default.aspx?id=EG

Van Loon L (2007) Plant responses to plant growth-promoting rhizobacteria. New perspectives and approaches in plant growth-promoting Rhizobacteria research. Springer, pp 243-254

Wu, Y., Liu, W., Li, X., Li, M., Zhang, D., Hao, Z., Weng, J., Xu, Y., Bai, L., Zhang, S., Xie, C. (2011) Low-nitrogen stress tolerance and nitrogen agronomic efficiency among maize inbreds: Comparison of multiple indices and evaluation of genetic variation. Euphytica **180** (2), 281.

Yadav, R.K., Verma, A., Yadav, S.L. and Sumariya, H.K. (2017) Dry Matter Partitioning at Harvest and Yield of Maize (*Zea mays* L.) as Influenced by Integration of Various Nutrients. Int. J. Curr. Microbiol. App. Sci., 6 (6): 2942-2945. https://doi.org/10.20546/ijcmas.2017.606.349

Yin, B.; Hu, Z.; Wang, Y.; Zhao, J.; Pan, Z.; Zhen, W. (2021) Effects of Optimized Subsoiling Tillage on Field Water Conservation and Summer Maize (*Zea mays* L.) Yield in the North China Plain. Agric. Water Manag., **247, 106732. [CrossRef]**

Zhao, B., Dong, S. T., Zhang, J. W. & Liu, P. (2013) Effects of controlled-release fertiliser on nitrogen use efficiency in summer maize. PLoS ONE **8**, e70569.

Gao, W., Yang, J., Ren, S. and Hailong, L. (2015) The trend of soil organic carbon, total nitrogen, and wheat and maize productivity under different long-term fertilizations in the upland fluvo-aquic soil of North China. Nutrient Cycling in Agroecosystems 103: 61-73. https://doi.org/10.1007/s10705-015-9720-7.

Qaswar, M., Jing, H., Ahmed, W., Dongchu, L., Shujun, L., Lu, Z., Cai, A., Lisheng, L., Yongmei, X., Jusheng, G. and Huimin, Z. (2020) Yield sustainability, soil organic carbon sequestration and nutrients balance under long-term combined application of manure and inorganic fertilizers in acidic paddy soil. Soil and Tillage Research 198: 104569. https://doi.org/10.1016/j.still.2019.104569.

Zhang, Y., Li, C., Wang, Y., Hu, Y., Christie, P., Zhang, J. and Li, X. (2016) Maize yield and soil fertility with combined use of compost and inorganic fertilizers on a calcareous soil on the North China Plain. Soil and Tillage Research 155: 85-94. https://doi.org/10.1016/j.still.2015.08.006.

تحسين إنتاجية الذرة من خلال استراتيجيات التسميد النيتروجيني المتكاملة: رؤى من تقنية النظير النيتروجيني المستقر (^{15}N)

محمد عدلى السيد سليمان[1]، محمود محمد محمد عبد السلام الشايب*[2]، أحمد عبد المنعم مرسى[2]
[1]قسم الأراضى والمياه، كلية الزراعة، جامعة دمياط، مصر
[2] قسم بحوث الأراضى والمياه، مركز البحوث النووية، هيئة الطاقة الذرية، أبو زعبل 13759، مصر
*المؤلف المراسل: love_m2028@yahoo.com

يعتبر النيتروجين عنصرًا غذائيًا حيويًا لتعظيم إنتاجية الذرة، وخاصة في المناطق القاحلة وشبه القاحلة التي تتميز بتدهور خصوبة التربة وندرة المياه. تهدف هذه الدراسة إلى تقييم فعالية استراتيجيات التسميد النيتروجيني المتكاملة، والجمع بين الأسمدة الكيميائية والعضوية والحيوية، لتحسين أداء الذرة. أجريت التجارب الميدانية باستخدام تصميم القطع المنشقة مرتين. تم اضافة النيتروجين الكيميائي على شكل يوريا مُوسومة بـ N-15، إما بمفرده أو بالاشتراك مع المحسنات العضوية ذات الأصل النباتي أوتلك المختلطة. كما تم اختبار الأسمدة الحيوية، بما في ذلك النيتروبين والسيريالين والفوسفورين. أشارت النتائج إلى أن اضافة معدل اليوريا بنسبة 75٪ يحسن بشكل كبير من محصول الحبوب وكفاءة استخدام النيتروجين (NUE٪) مقارنة بمعدل اليوريا بنسبة 50٪. في حين أن الجمع بين السماد العضوي أو الأسمدة الحيوية مع اليوريا يقلل قليلاً من محصول الحبوب، فإن جميع المعالجات التي تنطوي على اليوريا أو التعديلات العضوية أو الملقحات البكتيرية أسفرت عن زيادات كبيرة في الغلة مقارنة بمعاملة الشاهد غير المعالجة. وقد أكدت البيانات الناتجة من تطبيق تقانة النظير المستقر ^{15}N أن اليوريا كانت المصدر الأساسي للنيتروجين في الذرة، يليها السماد العضوي والأسمدة الحيوية. ومن بين التركيبات التي تم اختبارها، تفوقت اليوريا بنسبة 75% مع السماد العضوي المختلط والنيتروبين على غيرها، مما يدل على إمكاناتها كممارسة إدارة مثالية لتحسين إنتاجية الذرة في ظل سيناريوهات التسميد المختلفة.

الكلمات المفتاحية: الأسمدة العضوية الحيوية، التخفيف النظائرى، الإدارة المتكاملة، كفاءة استخدام النيتروجين، إنتاجية النبات، خصوبة التربة.