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Influence of Gamma Irradiation and Nitrogen Fertilization Levels on Growth and Yield of Maize (*Zea mays* L.) Grown on Sandy Soil

M. M. Ismail[1], E. A. Mousa[1], A. A. Moursy[1*] and M. A. Rizk[1]

[1]Department of Soil and Water Research, Atomic Energy Authority, Nuclear Research Center, Abou-Zaabl, 13759, Egypt.

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

A field experiment was carried out on sand soil using maize as a test crop exposed to different rates of N fertilizer and doses of gamma radiation. Response of maize to these exogenous factors was evaluated. Results revealed that, the irradiated (20 Gry) plants have higher grains (5.4 ton ha^{-1}) and lower stalks yield (17.533 ton ha^{-1}) than those of the non-irradiated plants (5.111 ton ha^{-1} and 18.867 ton ha^{-1}, respectively) fertilized with rate of 240 kg N ha^{-1}. In this respect, the relative increase or decrease was 5% and -7% over or lower the non-irradiated one, for the same sequence. Increasing gamma rays dose up to 40 Gry achieved higher grains and stalks yield (5.533 ton ha^{-1} and 18.778 ton ha^{-1}, respectively) than those recorded with the non-irradiated plants (5.111 ton ha^{-1} and 18.867 ton ha^{-1}, respectively) fertilized with rate of 240 kg ha^{-1}. Relatively, grains were approximately increased by about 7% over the non-irradiated plants while stalks yield was lowered by about 0.5%. It means that irradiation did not significantly, positively or negatively, affected the grain and/or stalks yield. Grain and stalks yields were highly significantly increased by increasing the N fertilizer levels as compared to the non-fertilized control.

**Corresponding author: E-mail: ahmad1a2m3@yahoo.com;*

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1. INTRODUCTION

Zea mays is one of the world's most important crop plants, boasting a multibillion dollar annual revenue. In addition to its agronomic importance, maize has been a keystone model organism for basic research for nearly a century. Within the cereals, which include other plant model species such as rice (*Oryza sativa*), sorghum (*Sorghum bicolor*), wheat (*Triticum* spp.) and barley (*Hordeum vulgare*), maize is the most thoroughly researched system. As a model organism, maize is the subject of far-ranging biological investigations such as plant domestication, genome evolution, developmental physiology, epigenetics, pest resistance, heterosis, quantitative inheritance, and comparative genomics [1].

Efficient nitrogen fertilization is essential for economic production and protection of the environment. Improvement in nitrogen use efficiency (NUE) has become a desirable goal in barley research. Nitrogen use efficiency in the crop is influenced by N uptake from the soil, N assimilation in the plant and N redistribution from vegetative parts to the grain [2].

Gamma rays have been proved economical and effective as compared to other ionizing radiations because of its easy availability and the power of penetration. This penetration power of gamma rays helps in its wider application for the improvement of various plant species [3].

Singh and Datta [4], pointed out that, gamma irradiation in low doses of 10 K rad had beneficial effect on growth and yield of wheat .The beneficial gamma rays dose in the research study of Mashev et al. [5], was determined to be 100 Gy, because of it's stimulatory effect on number of tillers per plant. Singh and Datta [6], observed that the low doses of gamma irradiation (0.01-0.10) KGy, improved plant vigour, flag leaf area, total number of tillers, number of ear biring tillers, grain number/spike and grain yield. Rahm Din et al. [7], used low dose gamma irradiation to improve grain development and yield attributes of wheat, also they affirmed the stimulatory effect of gamma irradiation on flag leaf area. Singh and Datta [6], ascertained that, gamma irradiation in high doses (30-35 K rad) had reducing effects on growth and yield of wheat. Studies on the effects of gamma-rays from ^{60}Co on wheat have been reported by Melki and Marouani [8]. Studies on alfalfa (*Medicago sativa* L.) [9], rice (*Oryza sativa* L.) [10] and okra (*Abelmoschus esculentus* Moench) [11] revealed that exposure to low doses lead to an increase of the assimilatory pigments content, while at high doses it decreases significantly as compared with non-irradiated ones. [12], [13], indicated that, wheat grains irradiated with low dose (10Gy) of Gamma radiation surpassed the other two irradiation doses (20 and 30 Gy) and the control in each of plant height(cm), spike length (cm), Flag leaf area (cm) at heading, number of spikes /m^2, number of spikelets/spike, number of grains / spikelet, grain weight/spike (g), grain weight/spikelet (mg), 1000- grains weight(g), grain, straw and biological yields/fad. Each increment in nitrogen supply caused significant increase in each above mentioned yield and yield components studied. Mohammad and Abdollah [14], showed that grain yield increased in response to application of gamma irradiation, as compared to the non-irradiated crop. 25 and 50 Gy gamma irradiation produced the highest grain protein content. Increasing in gamma irradiation being more than 50 Gy decreased grain protein by about 28% to 67%. Therefore, in this study, it was aimed to study the effect of gamma irradiation in low doses and nitrogen fertilizer levels on maize productivity grown on sandy soil.

2. MATERIALS AND METHODS

A field experiment was carried out at the Soil and Water Research Dept., Nuclear Research Center, Atomic Energy Authority, Inshas, Egypt.

2.1 Soil Physical and Chemical Analysis

The soil sample was collected, air dried ground and sieved to pass through 2 mm sieve then subjected to some physical and chemical analysis whose results are presented as following: A- Particle size distribution, coarse sand % 64.1, fine sand % 26.4, silt% 2.7, clay% 6.8, Textural class sand, B - Soluble cations and anions (m mol L^{-1}) in soil paste extract are, Ca^{2+} 1.25, Mg^{2+} 1.00, Na^{+} 0.32, K^{+} 0.09, CO_3^{2-}, HCO_3^{-} 0.88, Cl^{-} 1.25, SO_4^{2-} 0.53, p^H (1:2.5 soil suspension) 7.97, EC (paste extract) 0.27, organic matter 0.3 g kg^{-1} (OM). Total Nitrogen 0.07 g kg^{-1} (TN), C: N ratio 2.43, and $CaCO_3$ 10.0 g kg^{-1}.

2.2 Plant Materials

Maiz seeds (*Zea mays* L.) Hybrid 10, was provided by the Field Crop Research Institute, Agricultural Research Center, Giza, Egypt. A batch of dry seeds were exposed to different doses of gamma irradiation (0, 20 and 40 Gry), using gamma – rays generated from the Cobalt-60 source in the Irradiation Laboratory at Cyclotron Department, Nuclear Research Center, Atomic Energy Authority, Egypt.

2.3 The Experiment Layout

The experiment was laid out in randomized complete block design with four replicates in plots with area 3 x 1.5 m^2. Each plot having 3 rows, 50 cm row to row distance. Seeds were sown and fertilized with 0, 120 and 240 kg $ha^{-1}$of N as ammonium nitrate fertilizer. N was applied in split doses, half at sowing and the other at flowering stage. A basal dose of P and K was applied according to recommended rate in the form of single super phosphate and potassium sulphate.

The experimental design include 9 treatments replicated 4 times (equal to 36 plots), four doses of N applied and three doses of gamma rays treatments as following:1- (N0 R0) as a control, 2- (N0 R1) as N0 + 20 Gry,3- (N0 R2) as 0 kg N ha^{-1}+ 40 Gry., 4- (N1 R0) as 120 kg N ha^{-1}+ 0 Gry, 5- (N2 R0) as 240 kg N ha^{-1}+ 0 Gry, 6- (N1 R1) as 120 kg N ha^{-1}+ 20 Gry,7- (N2 R1) as 240 kg N ha^{-1}+ 20 Gry,8- (N1 R2) as 120kg N ha^{-1}+ 40 Gry,9- (N2 R2) as 240 kg N ha^{-1}+40 Gry.

Methods of analysis: Chemical and physical analysis of tested soil samples was carried out according to Page et al. [15] and [16]. Statistical analysis: The analysis of variance for the final data was statistically assayed using the system ANOVA and the values L.S.D from the controls were calculated at 0.05 levels according to SAS [17].

3. RESULTS AND DISCUSSION

3.1 Grains and Stalks Yield of Maize Plants

Data presented in Table 1, showed that, generally, in case of non-irradiated seeds, grains and stalks yields were significantly ($p<0.05$) affected due to increasing nitrogen fertilizer levels, while in case of irradiated seeds, grains and stalks yields did not significantly ($p>0.05$) affected due to the interaction between nitrogen fertilizer and gamma rays levels under all treatments. The overall means of fertilization and gamma rays effects under all treatments indicated that the highest values were 5.333 ton ha^{-1} and 18.400 ton ha^{-1}, and relatively increased by about 76.47% and 18.97% over untreated control for grains and stalks yield, respectively. However, under treatments of sole nitrogen fertilization, the highest values of grains and stalks yield were 5.111 ton ha^{-1} and 18.867 ton ha^{-1} observed in the plot received (240 kg ha^{-1}), relatively increased by 75.57% and 28.05% over unfertilized control for grains and stalks, respectively. Concerning the interaction effect, the highest values of grains and stalks yield were 5.533 ton ha^{-1} and 18.867 ta ha^{-1} , respectively recorded in the plot received (240 kg N ha^{-1} + 40 Gry gamma rays), and relatively increased by about 90.08% and 28.05% over the untreated control, respectively. In this regard, Farag and El-Khawaga [13], reported that wheat grain, straw and biological yields (ton/fed.), were insignificantly influenced by the interactions between gamma irradiation and nitrogen fertilizer levels. Wi et al. [18], reported no significant morphological aberration in the phenotype of plants irradiated with relatively low doses of gamma rays, while high-dose irradiation inhibited seedling growth remarkably.

3.2 N-uptake by Grains and Stalks

N-uptake by grains and stalks of non-irradiated seeds were significantly increased with increasing N fertilizer levels addition, whereas, in the case of irradiated one, the values of N-uptake by grains and stalks were significantly increased due to the interaction effect between gamma rays and N-fertilizer levels addition (Table 2). On the other hand, the overall means of fertilization and gamma rays effects under all treatments indicated that the highest values of N- uptake by grains (89.030 kg ha^{-1}) and stalks (130.689 kg ha^{-1}), relatively increased by about 52.36% and 28.15% over unfertilized control, respectively. However, under sole nitrogen fertilization, the highest values of N-uptake by grains (77.778 kg ha^{-1}) and stalks (124.244 kg ha^{-1}) observed in the plot treated with level of (240 kg N ha^{-1}), relatively enhanced by about 47.89% and 26.52% over non-irradiated unfertilized control. Concerning the interaction effect, the highest values of N- uptake by grains (101.422 kg ha^{-1}) and stalks (152.088 kg ha^{-1}) observed in the plot received levels of (240 kg N ha^{-1} + 20 Gry) and (240 kg N ha^{-1}+ 40 Gry), relatively increased by about 64% and 35% over non-irradiated unfertilized control, respectively.

In this regard, studies on rocket seedlings grown in clay loamy soil, [3], reported that, the macro-elements content, nitrogen and potassium increased at 20 Gy dose. Phosphorus content showed no significant effect at any of the 7-irradiation doses used. Kurdali et al. [19], reported that, a 10 Gy was found to be the optimal irradiation dose for enhancing N_2-fixation. High levels of NH_4^+-N decreased the percentage and the amount of N_2-fixation, but did not affect nodule formation. However, the presowing 10 Gy irradiation dose reduced the negative effect of ammonia-N fertilizer on N_2-fixation. Therefore, we recommend irradiating chickpea seeds with a 10 Gy dose before planting in soil containing high levels of mineral nitrogen to reduce its negative effect on N_2-fixation. An increase in nitrogen content was found by Maltseva and Kuzin [20] when *Vicia faba* seeds were irradiated with 0.1 and 10 k-rad of gamma rays.

3.3 P-Uptake by Grains and Stalks

P-uptake by grains and stalks as affected by gamma irradiation and nitrogen fertilization levels: Data presented in Table.3, showed that, generally, in the absence of gamma rays effect, there are no significant differences between the treatments for P-uptake by grains and stalks as affected by increasing N fertilizer levels addition, whereas, in the presence of gamma rays effect, the values of N-uptake by grains and stalks were significantly increased due to the interaction effect between gamma rays and N-fertilizer levels addition. Moreover, the overall means of nitrogen fertilization and gamma rays effects under all treatments "the main effect" the highest values of P- uptake by grains (24.378 kg ha-1) and stalks (51.074 kg ha-1), an increase of 51.92% and 31.56% over untreated without nitrogen fertilization, respectively. On the other hand, under treatments of sole nitrogen fertilization, the highest values of P-uptake by grains (23.378 kg ha-1) and stalks (52.356 kg ha-1) observed in the plot treated with level of (240 kg N ha-1), relatively enhanced by 52.46% and 37.18% over untreated without nitrogen fertilization. Concerning the interaction effect, the highest values of P- uptake by grains (27.356 kg ha^{-1}) and stalks (53.511 kg ha^{-1}) observed in the plot received levels of (240 kg N ha^{-1} + 40 Gry) and (240 kg N ha^{-1} + 40 Gry)), relatively increased by 48.66% and 31.69% over untreated without nitrogen fertilization, respectively.

Table 1. Effect of various doses (Gry) of gamma irradiation and N fertilizer levels on grains and stalks (ton ha^{-1}) yield of maize

N-fertilizer (kg ha^{-1})	Gamma irradiation doses (Gry)							
	Grains (ton ha^{-1})				Stalks (ton ha^{-1})			
	0 Gry	20 Gry	40 Gry	mean	0 Gry	20 Gry	40 Gry	mean
0 kg N ha^{-1}	2.911	2.6	3.587	3.033	14.733	15.6	16.067	15.467
120 kgN kg ha^{-1}	4.311	4.4	4.44	4.384	16.911	17.711	16.956	17.193
240 kg N ha-1	5.111	5.4	5.533	5.348	18.867	17.533	18.778	18.393
mean	4.111	4.133	4.52		16.837	16.948	17.267	
L.S.D at 5%	N	Gry	N* Gry		N	Gry	N* Gry	
level	0.71	0.69	0.8		1.58	1.26	1.04	

Table 2. Gamma irradiation effects on N-uptake by grains and stalks (kg N ha^{-1}) of maize plants under different nitrogen levels

N-fertilizer (kg ha-1)	Gamma irradiation doses (Gry)							
	Grains (kg ha-1)				Stalks (kg ha-1)			
	0 Gry	20 Gry	40 Gry	mean	0 Gry	20 Gry	40 Gry	mean
0 kg N ha-1	40.533	36.511	50.178	42.407	91.299	92.067	98.333	93.900
120 kg N kg ha^{-1}	61.113	67.067	70.444	66.208	115.044	111.578	108.444	111.689
240 kg N ha-1	77.778	101.422	87.889	89.030	124.244	115.756	152.089	130.696
mean	59.808	68.333	69.504		110.196	106.467	119.622	
L.S.D at 5% level	N	Gry	N* Gry		N	Gry	N* Gry	
	11.200	13.530	13.270		10.61	8.270	12.18	

Table 3. Gamma irradiation effects on P-uptake by grains and stalks (kg p ha^{-1}) of maize plants under different nitrogen levels

N-fertilizer (kg ha-1)	Gamma irradiation doses (Gry)							
	P-uptake by Grains (kg ha^{-1})				P-uptake by Stalks (kg ha^{-1})			
	0 Gry	**20 Gry**	**40 Gry**	**mean**	**0 Gry**	**20 Gry**	**40 Gry**	**mean**
0 kg N ha^{-1}	11.113	10.000	14.044	11.719	32.889	35.422	36.556	34.956
120 kg N kg ha^{-1}	16.578	17.711	18.444	17.578	38.067	51.356	52.200	47.208
240 kg N ha^{-1}	23.378	22.400	27.356	24.378	52.356	47.356	53.511	51.074
mean	17.023	16.704	19.948		41.104	44.711	47.422	
L.S.D at 5% level	N	Gry	N* Gry		N	Gry	N* Gry	
	3.480	2.920	4.430		3.850	5.270	4.400	

In this regard, studies on Chamomile (*Chamomilla recutit* L. Rauschert), Nassar et al. [21] reported that, gamma irradiation, alone increased phosphorus level in the shoots at 6 k-rad.Gamma irradiation was reported to affect the mineral content of several plants nitrogen and phosphorus contents of cabbage, onion and carrot were increased by 0.1 to 1.25 k-rad G.I. Deaf [22] reported an increase in nitrogen, phosphorus and potassium contents of lemongrass when seeds exposed to 1-4 k-rad G.I. Mahmoud [23] indicated that gamma irradiation (G.I.) increased phosphorus and potassium content of delphinium plants. Contradictory results were reported: a decrease in nitrogen content was found in *Capsicum annum* [24] and in *Datura innoxia* [25] when their seeds were exposed to G.I. In addition, Deaf [22] found a decrease in phosphorus percentage of lemongrass.

4. CONCLUSION

In this experimental study, maize crop was found to respond significantly to the application of N fertilizer and doses of gamma radiation in terms of the increase in grain yield and total dry biomass. As mentioned previously, concluded that, in the absence of gamma rays effect, grains and stalks yield of maize accumulated significantly increased with increasing N-fertilizer levels. This previous trend was observed with N-uptake by grains and stalks. In the contrary, P-uptake by grains and stalks did not significantly affected by increasing N-fertilizer levels. Whereas, in the presence of gamma rays effect, grains and stalks yield of maize accumulated significantly increased as a result of the interaction effect between gamma rays and N-fertilizer levels addition, these results were similar with N and P-uptake by grains and stalks.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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