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Effect of Potassium Fertilization Levels on Rice Yield, Yield Attributes and Rice Stemborer infestation of Giza 178 Rice Cultivar Grown under Nitrogen Fertilizer Levels

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RICE (*Oryza sativa* L.) and wheat are the main cereal crops in Egypt and all over the world. Unfortunately, several insect pests infest rice plans, and the stem borer, *Chilo agamemnon* Bles is the most important one in Egypt. The current investigation was carried out at the experimental farm of Rice Research and Training Center (RRTC), Sakha Agricultural Station, Kafr EL-Sheikh Governorate in 2021 and 2022 using Giza 178 rice cultivar (susceptible to rice stem borer). The study aimed to find out the effect of potassium fertilizer on rice yield, yield attributes as well as rice stem borer infestation in nitrogen-fertilized soils. Four levels of nitrogen (23, 46, 69 and 92 kg/fed) were laid out in the main plots while potassium fertilizer levels (0, 12, 24 and 36 kg/fed) occupied the sub plots. It was found that recommended application of nitrogen (69 kg Nfed^{-1}) and potassium (24 kg Kfed^{-1}) resulted in significant enhances in chlorophyll content, flag leaf area, plant height, number of panicle hill^{-1}, panicle weight, number of filled grains panicle^{-1}, and grain and straw yield. Grain yield was minimum (2.62 t fed^{-1}) in plots fertilized by 23 kg N fed^{-1}, and maximum (5.53 t fed^{-1}) in plots fertilized with recommended doses of each of nitrogen and potassium. Dead heart (DH) was 3.51% in the lowest nitrogenous fertilized plots, increased to 6.62% DH in plots fertilized with 92 kg N fed^{-1}(88.6% increase). Also, the lowest nitrogenous fertilized plots exhibited 3.79% white head (WH) in plots fertilized by 23 kg Nfed^{-1}, and 6.36% WH in plots that received 92 kg N fed^{-1}(67.81% increase). The reaction of rice plants took a reverse situation concerning potassium application. The DH% was highest (6.58%) in non-potassium fertilized plots and lowest (3.63%) in plots with 36 kg K fed^{-1}. Thus, the reduction in DH% was 44.83% due to potassium application. The corresponding value of WH% reduction was 54.63%. Chemical analysis revealed that the higher doses of nitrogen-potassium combinations resulted in to higher uptake of nitrogen, potassium as well as silica in rice stems. It could be concluded that the joint action of nitrogen and potassium promoted rice yield, its attributes, and reduced the rice stem borer infestation, versus the application of nitrogen alone.

Keywords: Potassium; Nitrogen; Rice; *Chilo agamemnon*; Silica Uptake.

1. Introduction

In Egypt, rice (*Oryza sativa*, L.) is a critical crop for food security, and comes next to wheat. For maximizing the crop productivity, fertilization with essential nutrients is necessary. The primary macronutrients are highly required in balance to achieve the greatest crop yield (Gewaily, 2019; Omara et al. 2022). However, wise application of nutrients is highly required in rice production for obtaining the highest yield, and lowest pest infestations. Rice plants given nitrogen fertilizer increases yield and yield components (Bala *et al*., 2018), but supplying plots with high doses of nitrogen, in the absence of potassium, results in rice lodging in some cultivars, which reflects 30 – 35 % yield reduction (Bhiah *et al.*, 2010). On the other hand, lack of potassium renders the rice plants more susceptible to insect pests (Bala *et al*., 2018). Bhiah *et al.* (2010) recommended application of potassium that increases tillering and thickness of shoots, and enhances root dry matter production by 80 - 300 %. Rice plants are subject to infestation, in Egypt, by several insect pests; stem borer, *Chilo agamemnon* Bles is a destructive one (Sherif *et al*. 2008). White heads are empty panicles resulting from invading the rice stem borer larvae to rice stems, and the annual rice yield losses due to insect infestation were estimated as 8 – 10 % (El-Malky *et al*. 2013). The nutritional status of plants influences the attractiveness stem borer to rice plants (Aziz *et al.* 2018). Because the growers are usually excited about insect infestation symptoms, they tend to apply insecticides. Adverse effects of infestation on the environment and human-being are well known, so insect damage should be managed without or with least insecticide application as possible. Bala *et al*. (2018), and Farid et al., (2023) reported that application of potassium improves the formation of

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secondary metabolites, and reduces the plant contents of carbohydrates, which reflects less damage of insect pests to the plants. Cakmac (2005) concluded that high potassium contents in plant tissue increase its resistance to abiotic stresses such as environmental variations like temperature stress, rain, cold and frost, and biotic stress like pests and diseases. Bala *et al*. (2018) indicated that rice stem borer population density could be suppressed by the combination of potassium and nitrogen fertilizer in the proper rate. Potassium application enhances absorption and concentration of nitrogen and silica by rice plants. These high levels of silica increase thickness of leaves to become more tolerant to insects and fungi (Zehng *et al* 2021).

Investigating the impact of potassium treatment on rice yield and yield characteristics, as well as on rice stem borer infestation of rice Giza 178 cultivar produced on nitrogen-fertilized soils, were the goals of the current study.

2. Materials and Methods

Experimental site and tested cultivar

During 2021 and 2022 rice growing seasons, field tests were conducted at the Experimental Farm of the Rice Research and Training Center (RRTC), Sakha, Kafr El-Sheikh, Egypt. The goal was to find out how potassium fertilizer affects rice productivity and how susceptible Giza 178 rice cultivar was to stem borer infestation. El-Kady (2015) lists the features of the Giza 178 rice cultivar in Table 1. To assess the impact of different fertilizer treatments on borer infestation of rice, the vulnerable Giza 178 rice cultivar was chosen, according to RRTC (2018).

Experimental design

Three replicates of the split plot design were used. Four levels of nitrogen fertilization were used in the main plots, whereas four levels of potassium fertilization were used in the sub plots.

Table 1. Characteristics of Giza 178 rice cultivar.

Item	Description
Parents	Giza175/Milyang 49
Origin	Egypt
Growth duration	135 days
Plant height	99 cm
Number of tillers (hill)	22.19
Panicle length	21.0 cm
Fertilizer	69 kg N /fed.
Reaction to insects	Susceptible
Productivity	4 – 5 t /fed.
1000-grain weight	21 g
Hulling %	80.1%
Milling %	70.0 %
Head rice %	66.0 %

Nursery preparation

The seed bed was ploughed three times, with incorporating calcium super phosphate (15.5% P_2O_5) at a rate of 4 kg per 175 m^2 with the final plough. Prior to dry levelling, urea (46.5% N) was added to the soil at a rate of 3 kilograms per 175 m^2. Prior to grain sowing, one kilogram of zinc sulphate (24 % $ZnSO_4$) was added after wet levelling. On May 2nd of 2021 and 2022 growing seasons, Giza 178 rice seeds were distributed at a rate of 60 kg/fed., after being soaked in fresh water for 48 hours, incubated for an additional 48 hours, and then planted. Thiobencarb (Saturn 50EC), at a rate of two liters/fed., was applied at the stage of 3-leaf seedling**.**

Permanent field preparation

The permanent field was tilled three times, with 100 kg/fed. of calcium super phosphate (15.5% P_2 O_5) added before the final tillage. Urea (46.5% N) was used as the nitrogen fertilizer, and it was applied in three equal separate amounts: 1/3 as basal (incorporated into the soil before puddling), 1/3 after 20 days, and the final third after 40 days. Potassium fertilizer, K_2 SO_4 (48% K_2O), was applied in two portions: one half as basal application (incorporated into the soil before puddling), and one half just prior to panicle initiation. After the seeds were sown, the seedlings were pulled out after 30 days, planted in the permanent field, at 20 x 20 cm apart with 3–4 seedlings per hill. Four levels of nitrogenous fertilization were applied as follows: 23, 46, 69 and 92 kg/fed, in the form of urea. Four levels of potassium fertilization were applied as follows: 0, 12, 24 and 36 kg/fed, in the form of potassium sulphate (48 % K_2O). All plots received the normal dose of phosphorous; 15.5 % kg/fed.

Studied characteristics

After complete maturity, total number of panicles in five random hills were counted in the field, and calculated as the number /m^2. Also, ten panicles were randomly collected from each plot, air dried and weighed, in the same time, panicle length, panicle weight, total number of filled grains and weight of 1000 grains were recorded. Plants of an area of 6 m^2 (150 hills) of each plot were manually harvested according to the harvest time of the cultivar. On the basis of 14% moisture content, the weight was adjusted to ton / fed.

Evaluation of stem borer, *Chilo agamemnon* Bles. infestation

The plants were evaluated for the dead heart symptom 40 days after transplantation. Five random hills were cut at the soil surface from each plot. The total number of tillers and the number of dead hearts were counted, and the percentage of dead hearts was then determined. White head percentages were calculated three weeks before harvest. Five hills were cut at the soil surface from each plot. The total number of tillers and those with white heads were counted, and the percentage of white heads was then determined.

Uptake of nitrogen, potassium and silica in stems

Following harvest, 15 rice stems per plot were cut and placed in paper bags and oven dried for 48 hours at 70°C. After being dried, the samples were finely powdered and chemically digested using Chapman and Pratt (1962) procedure. Method of Page et al. (1982) was used to determine the potassium concentration, and Snyder (2001) to determine the silica concentration. The micro-kjeldahl method was used to determine the nitrogen concentration. Plant samples were chemically analyzed in the National Research Center laboratory.

Statistical analyses

Data were subjected to the standard statistical analysis with COSTAT. The significantly differed means were compared using Duncan's Multiple Range Test (1955).

3. Results and Discussion

1. Effect of nitrogen-potassium fertilizer combinations on yield and yield attributes

Data in Table (2) demonstrates how the Giza 178 rice cultivar vegetative development properties are affected by the quantities of nitrogen and potassium fertilization. Chlorophyll contents in plots fertilized with 23 kg N|feddan were 35.97 and 37.06, flag leaf areas were 16.65 and 17.63 cm^2, and plant heights were 87.13 and 88.04 cm, respectively, in 2021 and 2022 seasons. These values gradually increased as nitrogenous dosages increased, reaching a maximum of 69 kg N/fed. The maximum values of the aforementioned features were attained with 92 kg N/feddan in of 2021 and 2022 seasons, with 42.63 and 42.47 for chlorophyll contents, 40.41 and 41.82 cm^2 for flag leaf areas, and 109.30 and 108.78 cm for plant heights, respectively. Significant differences were calculated.

Concerning potassium levels, the abovementioned traits took the same trend, being highest with 36 kg K/feddan, and decreased gradually as the levels of potassium decreased, to exhibit the lowest values in non-potassium fertilized plots, or those fertilized with 12 kg K/feddan. Also, statistical analysis revealed highly significant differences due to variable levels of potassium fertilizer. The increase in abovementioned traits due to potassium application may be due to the role of potassium which plays a vital role in crop growth and metabolism. These results are in agreement with those of **Gorgy *et al*. (2009) and (Gewaily 2019).**

Interaction between nitrogen and potassium fertilizers significantly affected the flag leaf area and plant height (Table 3). In 2021, the highest flag leaf area (43.30 cm^2) occurred with the application of 92 kg N/fed, with 24 kg K, followed by 41.70 cm^2 in case of 69 kg N and 36 kg K. without a significant difference. However, no significant differences in flag leaf areas were found with the application of 92 kg N/feddan, combined with 12, 24 or 36 kg K/ feddan, or application of 69 kg N combined with 24 or 36 kg K/fed. A similar trend was found in 2022 season. The highest flag leaf areas; 45.0, 44.1, 43.5 and 43.2 cm^2 were recorded with the application of 69 or 92 kg N/fed, combined with 24 or 36 kg K/ feddan. These values were not significantly different.

As for plant height, the greatest values in 2021 (Table 3) were 111.4, 110.3 and 110.1 cm in case of 92 kg N with the application of 24 or 36 kg K, followed by 69 kg N combined with 24 or 36 kg K/feddan, respectively, without a significant difference. In 2022 season, fertilization with 92 kg N combined with 24 or 36 kg K/ feddan produced the highest plants, 109.2 and 109.8 cm, without a significant difference. The increase in flag leaf area could be attributed to the increased amount of nitrogen fertilizer which increases the plant vegetative growth by enhancing cell division **(Zaman *et al*., 2015)**. Potassium fertilization also improves the flag leaf area and plant height by improving its metabolism. Similar results were achieved by **Shakouri *et al*. (2012).**

Table 2. Effect of nitrogen and potassium fertilization and their interaction on some vegetative growth attributes of Giza 178 rice cultivar

Main effect and interaction	Chlorophyll content		Flag leaf area (cm)		Plant height (cm)	
	2021	2022	2021	2022	2021	2022
N level (kg/fed)						
23	35.97 b	37.08 d	16.65 d	17.63 d	87.13 d	88.04 d
46	37.75 b	39.06 c	28.61 c	30.01 c	100.22 c	102.17 c
69	40.40 a	41.34 b	37.54 b	40.01 b	106.51 b	106.98 b
92	41.63 a	42.47 a	40.41 a	41.82 a	109.3 0 a	108.78 a
F test	**	**	**	**	**	**
K level (kg/fed)						
0	37.18 c	37.80 c	27.83 c	29.35 c	97.34 d	99.93 d
12	38.77 b	39.26 b	29.56 b	30.89 b	99.62 c	100.72 c
24	39.76 a	41.12 a	33.09 a	34.85 a	102.15 b	102.35 b
36	40.05 a	41.70 a	32.73 a	34.47 a	104.04 a	102.95 a
F test	**	**	**	**	**	**
Inter. N X K	**ns**	**ns**	**	*	**	**

Means within a column followed by the same letter do not differ significantly ($P < 0.05$) according to Duncan's Multiple Range Test.

Table 3. Effect of interaction between nitrogen levels and potassium fertilization on flag leaf area and plant height of Giza 178 rice cultivar.

N level kg /fed	2021				2022			
	K level (kg/fed)							
	0	12	24	36	0	12	24	36
	Flag leaf area (cm^2)							
23	14.0 f	15.8 ef	17.9 e	19.0 e	15.3 g	16.7 fg	18.9 f	19.7 f
46	26.7 d	28.7 d	29.9 d	29.2 d	27.6 e	29.9 de	31.6 d	31.4 d
69	33.2 c	33.9 c	41.3 a	41.7 a	35.3 c	37.2 bc	44.1 a	43.5 a
92	37.4 b	39.9 ab	43.3 a	41.1 a	39.2 b	39.8 b	45.0 a	43.2 a
	Plant height (cm)							
23	84.1 m	85.7 l	87.3 k	91.4 j	85.7 k	87.1 j	89.2 i	90.2h
46	95.6 i	98.3 h	102.6 g	104.4ef	101.2g	101.4 g	102.5 f	103.5e
69	103.3 fg	105.3de	107.3 c	110.1ab	105.2 d	105.8 d	108.6bc	108.3bc
92	106.3cd	109.2 b	111.4 a	110.3ab	107.6c	108.5bc	109.2ab	109.8a

Data presented in Table (**4**) show the effect of different nitrogen and potassium fertilization rates on some yield attributes of Giza 178 rice cultivar.

Number of panicles and panicle weight

The highest number of panicles hill^{-1} and greatest weight of panicle were detected with the highest rate of nitrogen (92 kg N/fed), while the least value was those in the lowest rate of nitrogen (23 kg N|fed) or in plots fertilized with a rate of nitrogen (46 kg N/fed). Significant differences were recorded among the variable rates of nitrogen. Nitrogen application and balance fertilization is a very effective factor in tillering capacity **(Yadanar *et al.* 2018)**.

As for potassium levels, the highest numbers of panicles hill^{-1} were obtained with 24 and 36 kg K/feddan, while the lowest numbers were recorded with zero or 12 kg K/fed. The same trend was found in case of panicle weight. **Yang *et al*. (2005)** indicated that rice roots greatly modify potassium mobility in the rice rhizosphere which ultimately enhances potassium uptake and activate the nodes to emerge more tillers, consequently more panicles. Also, potassium as co-activator in the enzymes, causes a fast translocation of the metabolites form source to sink of plant that increases the filling of spikelets, consequently, increases the weight of panicles **(Ramos *et al*. 1999).**

The interaction effects of nitrogen and potassium on some yield attributes are presented in Table (**5**). In 2021 season, the plots having 92 kg N and 24 kg K/feddan produced the highest number of panicles hill^{-1} (33.30) and significantly exceeded all other combinations, followed by 31.63 panicles at 69 kg N combined with 24 kg K/feddan. In 2022 season, the highest numbers of panicles per hill (29.40) were obtained at 69 kg N + 24 kg K and at 92 kg N combined with 24 kg K (30.53) or 36 kg K (29.80). The three values did not differ significantly.

Concerning panicle weight (Table **5**), in 2021 rice season, the heaviest panicles were obtained with 69 or 92 kg N/feddan, combined with 12, 24 or 36 kg K/feddan, as well as 46 kg N + 36 kg K, all without significant differences. In 2022 season, the highest values of panicle weight were obtained with 24 or 36 kg K/feddan, combined with 46, 69 or 92 kg N/fed, all without significant differences. **Rajeev Kumar *et al*. (2013)** indicated that number of panicles, number of grains per panicle, filled grain percentage, grain and biological yield were significantly affected by nitrogen and potassium combinations.

1000-grain weight

The greatest 1000-grain weight was 21.22 g in the 2021 season and 21.17 g in the 2022 season, both with 46 kg N/fed, whereas the lowest values were achieved with the lowest fertilized plots or those fertilized at the highest rate (92 kg N/fed). The 1000-grain weight was dramatically lowered by nitrogen application. This is mainly because plants that received nitrogen at any rate had more spikelets per panicle than plants that didn't receive nitrogen. As a result, the filling of grains will be more and the weight of grains will be greater because the sink has a high capacity and the source is limited. Metwally *et al.* (2011) achieved similar outcomes. A genetic characteristic, 1000-grain weight varies between cultivars and is influenced by maturity conditions. 1000-grain weight differed with highly significant differences due to potassium fertilizer treatments. The highest values of 1000-grain weight were obtained at potassium of 36 kg /fed., followed by those at 24 kg K/fed. while the lowest values were recorded in the control (without potassium). These results are in harmony with those obtained by **Gewaily (2019) and Saha *et al.* (2009)** who reported that application of K basally work as co-factor for plenty of transferring enzymes. These enzymes improve the rate and percentage of filling, consequently, increase number of filled grains, panicle weight and 1000-grain weight resulting in an increase in grain yield.

According to analysis in Table (5) to the interaction between nitrogen and potassium fertilizers, 46 kg N + 36 kg K/fed in 2021 had the greatest significant value of 1000-grain weight (21.90g). The maximum 1000-grain weight values during 2022 season were at 46 kg N combined with 12, 24 or 36 kg K, at 69 kg N combined with 24 or 36 kg K, or at 92 kg N combined with 24 kg K. According to Rajeev Kumar et al. (2013), the interaction impact of N and K was significant for the harvest index, biological yield, filled grain percentage, and number of grains per panicle. Nitrogen and potassium top-dressing enhanced plant potassium content, grain filling, and straw yield.

Total number of grains/panicle

The highest value of total number of grains per panicle were found with 92 kg N/feddan, followed by 69 kg N/fed., while the lowest values were found with the lowest fertilized plots in the first and second seasons.

As for potassium levels, the highest value of total number of grains per panicle was obtained with 36 kg K/feddan, while the lowest value was recorded with zero and 12 kg K/fed in both seasons.

In 2021, the highest numbers of grains/panicle (189.9) (Table **5**) were due to interaction between 69 or 92 kg N/feddan (189.9) combined with 24 kg K/feddan, and 69 or 92 kg N/feddan combined with 36 kg K/feddan (193.10 and 194.8). In 2022, the highest numbers of grains panicle^{-1} were usually obtained with the highest rate of nitrogen as combined with either dose of potassium.

Filled grain percentage

Regarding percentage of filled grains, the lowest values were found with 92 kg N/feddan, while the highest were found with non-fertilized plots. Increased rate of nitrogen, resulted in a significant increase in number of unfilled grains per panicle, this might be due to production of more spikelets per plant and photo-assimilation. These results are similar to those obtained by **Gewaily *et al.* (2018).**

As for potash fertilizers, data showed that application of any potash treatment resulted in an increase in the percentage of filled grains compared to the control. The percentage of filled grains was highest when plants were fertilized with 36 kg K/February, followed by 24 kg K/fed, without a significant difference between both seasons.

Table 4. Effect of nitrogen levels and potassium fertilization on some rice yield attributes of Giza 178 rice cultivar.

Main effect and interaction	Panicles/ hill		Panicle weight (g)		1000-grain weight (g)		Total No. grains /panicle		Filled grain %	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
N level (kg/fed)										
23	20.03 d	18.7 d	2.89 d	2.98 d	20.25c	20.11 c	135.5 c	137.1 d	97.1 a	96.3a
46	26.7 c	25.3 c	3.51 c	3.47 c	21.22a	21.17a	156.1 b	155.0 c	95.1 bc	95.2 b
69	29.2 b	27.7 b	3.79 b	3.74 b	20.75b	20.93ab	183.5 a	180.5 b	95.6 b	95.4 b
92	30.4 a	29.2 a	4.02 a	3.93 a	20.24c	20.56b	187.2 a	191.4 a	94.5 c	94.0 c
F test	**	**	**	**	**	**	**	**	**	**
K level (kg/fed)										
0	24.03 d	23.35 d	3.11 c	2.99 d	19.92d	20.12c	150.5 d	153.4 d	93.7 c	93.0 c
12	25.64 c	24.64 c	3.59 b	3.50 c	20.46c	20.60b	162.9 c	159.6 c	95.6 b	95.3 b
24	28.72 a	26.90 a	3.73 a	3.77 b	20.85b	21.05a	171.6 b	170.2 b	96.4 a	96.3a
36	27.93 b	25.7 b	3.77 a	3.87 a	21.24a	20.98a	177.1 a	180.9 a	96.7 a	96.4 a
F test	**	**	**	**	**	**	**	**	**	**
Inter. N X K	**	**	*	**	**	**	**	**	**	**

Means within a column followed by the same letter do not differ significantly ($P < 0.05$) according to Duncan's Multiple Range Test.

Table 5. Some yield attributes as affected by the interaction between nitrogen and potassium levels of Giza 178 rice cultivar.

N. level kg /fed	2021				2022			
	K level (kg/fed)							
	0	12	24	36	0	12	24	36
				Panicle hill^{-1}				
23	18.03j	19.10 i	21.73h	21.26 h	17.70 i	18.50hi	19.80 g	18.90gh
46	23.90g	25.40 f	28.20e	29.33de	22.43 f	23.64 e	27.90 c	27.09c
69	26.00 f	28.63de	31.63b	30.50 c	25.70 d	27.30 c	29.40ab	28.40bc
92	28.23 e	29.50 d	33.30 a	30.63 c	27.63 c	29.20 b	30.53 a	29.80ab
				Panicle/ weight (g)				
23	2.55 g	2.90 f	2.98 f	3.14ef	2.45 h	2.86 g	3.21 f	3.42 e
46	2.92 f	3.45 d	3.77bc	3.88a-c	2.78 g	3.59de	3.68 cd	3.85bc
69	3.27de	3.93a-b	4.04a-c	3.93a-c	3.18 f	3.67cd	4.01 ab	4.10 a
92	3.71 c	4.08ab	4.15 a	4.14 a	3.56de	3.86bc	4.20 a	4.09 a
				1000-grain weight (g)				
23	19.6f	19.8f	20.4de	21.2bc	19.7g	19.9fg	20.3d-f	20.5de
46	20.4de	21.1bc	21.5b	21.9a	20.8b-d	21.3ab	21.4a	21.2a-c
69	20.2e	20.6de	20.9cd	21.3bc	20.2ef	20.8b-d	21.1ac	21.5a
92	19.5f	20.3e	20.6de	20.5de	19.7g	20.4de	21.3a	20.7c-e
				Total grains panicle^{-1}				
23	118.9 j	137.1hi	139.9hi	146.2 gh	125.8 l	133.1 k	138.6 k	151.0i
46	131.3 i	151.6g	166.7f	174.6 d-f	136.7 k	144.3 j	161.5 h	177.6ef
69	171.0ef	180.0c-e	189.9a-c	193.1 ab	168.7 g	174.4 f	186.7cd	192.3bc
92	180.8c-e	183.1b.d	189.9a-c	194.8 a	182.2de	186.9cd	194.1b	202.6a
				Filled grain %				
23	96.3ab	96.7ab	97.8 a	97.7 a	95.1cd	95.7 bc	97.1ab	97.2 a
46	93.1 d	95.5 b	95.6 b	96.2ab	93.2 e	95.0cd	95.8bc	96.9ab
69	94.0cd	95.7b	96.2ab	96.5ab	93.3 e	96.1a-c	96.2a-c	96.1a-c
92	91.3 e	95.1 bc	95.8 b	96.1ab	90.4 f	94.4d	95.9a-c	95.3cd

A similar trend was found by Gewaily, (2019). Ranamukhaarachchi and Ratnayake (2006) indicated that plots receiving K near to grain filling stage had a higher number of filled grains compared to corresponding treatments without potassium fertilizer.

The interaction between nitrogen and potassium levels (Table 5) revealed that the highest significant values of filled grain percentages were obtained with zero nitrogen combined with any of potassium levels, as well as with 36 kg K combined with any of nitrogen levels in 2021 season. In 2022 season, the highest values of filled grain percentages were obtained in non-nitrogen fertilizer plots combined with 24 or 36 kg K/feddan, or at 36 kg K combined with 46 kg N/fed. In addition, the treatment of 69 kg N/feddan combined with 12, 24 or 36 kg K produced the highest percentage of filled grains.

Grain yield t/fed

The highest grain yields (Table **6**) were obtained at 92 kg N/fed, (5.44 and 5.34 t/fed.) followed by 69 kg N/fed (5.11 and 4.96 tons/fed.) in 2021 and 2022 seasons, respectively. The same trend was found with potassium levels, highest (4.73 and 4.56 t/fed.) at 36 kg K and 4.62, 4.51 at 24 kg K/fed, in the first and second seasons, respectively. Highly significant differences were recorded among the variable levels of nitrogen and potassium.

Interaction effect of nitrogen and potassium on grain yield was significant (Table **7**). In 2021 season, the interaction between 92 kg N and 24 or 36 kg K and between 69 kg N and 36 kg K/fed, produced the highest grain yield. In 2022 season, the greatest value of grain yield was that obtained at 92 kg N + 24 kg K (5.57 t/fed). Combined application of K and N had a clear positive effect on grain and straw yield, and was an important approach in improving K use efficiency **(Li *et al.* 2009).**

Straw yield

Straw yield was highest (6.71 and 6.69 t/fed) in plots fertilized with the highest rate of nitrogen (92 kg/fed), followed by (6.24 and 6.20 t/fed) in case of 69 kg N/fed (Table **6**). However, the lowest straw yield (4.12 and 4.23 t/fed) was detected in 23 kg N fertilized plots in 2021 and 2022 seasons, respectively. The potash fertilization took the same trend, with the highest value in case of 36 kg K, followed by 24, 12 kg K/fed. The least straw yield was recorded in non-potassium fertilized plots.

The interaction between nitrogen and potassium (Table **7**), in 2021 season, resulted in the highest significant straw yield in case of 92 kg N combined with 24 or 36 kg K/fed, with values of 6.86 and 7.05 t.fed, respectively. In 2022 season, the highest significant straw yield (7.11t/fed) was recorded in the treatment of 92 kg N + 36 kg K/fed. Potassium plays an important role in ensuring efficient utilization of nitrogen. Joint application of potassium and nitrogen was found very necessary to obtain high-yielding varieties **(Meena *et al.* 2002).** **Harvest index**

The harvest index was highest with the high levels of nitrogen (69 or 92 kg/fed) and high levels of potassium (24 or 36 kg K/fed).

Table 6. Grain, straw yield and harvest index as affected by nitrogen and potassium levels and their interaction.

Main effect and interaction	Grain yield (t/fed.)		Straw yield (t/fed.)		Harvest index	
	2021	2022	2021	2022	2021	2022
N level (kg/fed)						
23	2.91 d	2.89 d	4.12 d	4.23 d	41.30 c	40.5 c
46	4.26 c	4.11 c	5.63 c	5.37 c	43.0 b	43.2 b
69	5.11 b	4.96 b	6.24 b	6.20 b	45.0 a	44.7 a
92	5.44 a	5.34 a	6.71 a	6.69 a	44.8 a	44.4 a
F test	**	**	**	**	**	**
K level (kg/fed)						
0	4.10 d	4.05 c	5.45 c	5.48 b	42.5c	42.1 b
12	4.31 c	4.20 b	5.54 c	5.59 b	43.3 bc	42.6 b
24	4.62 b	4.51 a	5.73 b	5.58 b	44.0ab	44.2 a
36	4.73 a	4.56 a	5.98 a	5.84 a	44.3 a	43.6 a
F test	**	**	**	**	**	**
Inter. N X K	**	**	*	*	ns	ns

Means within a column followed by the same letter do not differ significantly ($P < 0.05$) according to Duncan's Multiple Range Test.

Table 7. Effect of the interaction between nitrogen and potassium levels on grain and straw yield of Giza 178 rice cultivar.

N. level kg /fed	2021				2022			
	K level (kg/fed)							
	0	12	24	36	0	12	24	36
	Grain yield (t/fed.)							
23	2.62 i	2.74 i	3.05 h	3.19 h	2.71 i	2.80 hi	2.94 gh	3.11 g
46	3.70 g	4.25 f	4.44 e	4.65 d	3.67 f	3.98 e	4.32 d	4.45 d
69	4.79 d	4.85 d	5.26 c	5.54ab	4.65 c	4.78 c	5.13 b	5.29 b
92	5.23 c	5.32 bc	5.68 a	5.53 ab	5.17 b	5.23 b	5.57 a	5.37 b
	Straw yield (t/fed.)							
23	3.92 g	4.12 g	4.19 g	4.25 g	4.24 g	4.20 g	4.21 g	4.28 g
46	5.27 f	5.55 e	569 e	6.02 d	5.07 f	5.38 e	5.52 e	5.53 e
69	6.17 cd	6.02 d	6.19 cd	6.59 b	6.16 cd	6.17 cd	6.01 d	6.46 bc
92	6.46bc	6.48 bc	6.86 a	7.05 a	6.44 b	6.58 b	6.61 b	7.11 a

2. Effect of nitrogen and potassium fertilization on rice stem borer infestation

Two symptoms of rice stem borer, *Chilo agamemnon* Bles. were considered; dead hearts and white heads.

Dead heart

Average of dead hearts progressively and significantly increased as the nitrogenous doses increased, with values of 3.51, 4.12, 5.28 and 6.62% at 23, 46, 69 and 92 kg N/fed, respectively (Table **8**).

Thus, the dead heart averages increased by 88.60 and 50.45% at 92 and 69 kg N/fed, as compared to the control treatment. Increase of nitrogenous fertilizer in rice fields may increase the succulence of stems and leaves **(Ramazan *et al.* 2007)**. **Sultan *et al.* (2013)** indicated that high levels of nitrogenous fertilization lead to a greater stem borer attack, higher larval weight, and meanwhile shorter development duration of stem borer.

The potash fertilization induced a reverse situation. The high doses resulted in low significant levels of dead hearts, with averages of 6.68, 4.69, 3.80 and 3.63 % in case of 0, 12, 24 and 36 kg K/fed, respectively. This means reductions in dead hearts by 28.72, 42.25 and 44.83 % at 12, 24 and 36 kg K/fed, respectively compared to the control. Similar results were obtained by **Sarwar (2012). Zaman *et al.* (2015)** reported that application of potassium fertilizer improves plant parameters such as basal internode space, cellulose content, stem-fiber and silica content. They indicated that high silica content in stems may contribute to stem strength against insect penetration.

White heads

Average of white heads took the same trend, with values of 6.36, 5.85, 4.44 and 3.79 % at 92, 69, 46 and zero kg N/fed, respectively (Table 8). The increase in values of white heads were 67.81 and 54.36% in plots fertilized with 92 or 69 kg N/fed, respectively. **Kulagod *et al.* (2011)** reported that excessive use of nitrogenous fertilizers increased rice stem borer incidence. They added that the higher water content in rice stems and leaves facilitates uptake of higher nitrogen levels, which encourages the rice stem borer larvae to penetrate the rice stems.

As with dead hearts, the high doses of potassium fertilizer reduced the levels of white heads. Averages were 7.67, 5.40, 3.87 and 3.48 % at 0, 12, 24 and 36 kg K/feddan, respectively. Thus, the reductions were 29.60, 49,54 and 54.63 % due to 12, 24 and 36 kg K/feddan, respectively. The application of potassium levels reduced significantly white head percentage. This phenomenon was explained by **Bala, *et al*. (2018)** who indicated that the insect infestation reduction might be due to reduction in carbohydrate accumulation and increase in hardness of plant tissues.

Interaction between nitrogen and potassium affected significantly on both dead hearts and white heads in both seasons (Table **9**). The highest values of dead hearts (8.92 and 7.17 % in 2021 and 7.75 and 7.57 % in 2022 seasons were obtained with 92 kg N/fed in the absence of potassium, while the lowest dead hearts were obtained with 24 or 36 kg K/fed in the absence of nitrogen fertilizer. The same trend was obtained with white heads. **Bala *et al*. (2018)** suggested that proper application of potassium and nitrogen fertilizers should be beneficial to controlling insect pests. Increase in potassium concentration in the stems of rice plants led to a high uptake of silica in the stems, which led to an obstruction and a delay in penetration of the stem-piercing larvae into the rice stems and exposed them to vital enemies and unfavorable natural factors.

Table 8. Effect of nitrogen and potassium levels on rice stem borer as dead hearts and white heads of Giza 178 rice cultivar.

Main effect and interaction	Dead heart %				White head %			
	2021	2022	Average	Increase%	2021	2022	Average	Increase %
N level (kg/fed)								
23	3.30 c	3.72 b	3.51	--	3.51 b	4.07 d	3.79	--
46	3.93 b	4.30 b	4.12	17.38	3.67 b	5.21 c	4.44	17.15
69	4.98 a	5.57 a	5.28	50.43	5.33 a	6.35 b	5.85	54.36
92	5.13 a	6.10 a	6.62	88.60	5.41 a	7.30 a	6.36	67.81
F test	**	**	-	-	**	**	-	-
K_2o (kg/fed)								
	2021	**2022**	**Average**	**Reduction%**	**2021**	**2022**	**Average**	**Reduction %**
0	6.30 a	6.85 a	6.58	--	6.39 a	8.95 a	7.67	--
12	4.05 b	5.33 b	4.69	28.72	4.77 b	6.02 b	5.40	29.60
24	3.62 bc	3.97 c	3.80	42.25	3.57 c	4.17 c	3.87	49.54
36	3.39 c	3.87 c	3.63	44.83	3.21 c	3.75 c	3.48	54.63
F test	**	**	-	-	**	**	-	-
Inter. N X K	**	**	-	-	**	**	-	-

Means within a column followed by the same letter do not differ significantly ($P < 0.05$) according to Duncan's Multiple Range Test.

Table 9. Dead hearts and white heads percentage as affected by the interaction between nitrogen and potassium fertilizer levels of Giza 178 rice cultivar.

N. level kg /fed	2021				2022			
	K_2So_4 level (kg/fed)							
	0	12	24	36	0	12	24	36
				Dead heart %				
23	3.98 cd	3.20 cd	3.05 cd	2.95 d	4.72 cd	4.18 de	2.73 g	3.24fg
46	5.03 c	3.67 cd	3.58 cd	3.44 cd	5..83 b	4.46 c-e	3.20 fg	3.65 ef
69	7.17 b	4.76 cd	4.37 cd	3.65 cd	7.57 a	5.38 bc	4.49 c-e	4.79 cd
92	8.92 a	4.61 cd	3.49 cd	3.51 cd	7.75 a	7.28 a	5.10b-d	4.21 de
				White head %				
23	4.85 cd	3.97 de	3.19e-g	2.69fg	5.65ef	3.98 gh	3.22 h	3.41 h
46	4.59 cd	4.02 de	2.43 g	2.98e-g	7.34cd	5.62 ef	4.15gh	3.73 gh
69	7.63 b	5.54 c	4.73 cd	3.71d-f	10.89 b	6.61 de	4.31 gh	3.59 h
92	8.47 a	5.52 c	3.92 de	3.43e-g	11.96 a	7.90 c	5.01fg	4.27gh

Absence or low doses of potassium results in succulent rice stems, which encourages the penetration of stem borer to rice stems, reflecting high levels of dead hearts and white heads. This result agrees with that of **Bala *et al.* (2018).** In the same trend, **Bhiah *et al.* (2010)** recommended potassium application to enhance the thickness of rice stems to retard the penetration of borer larvae to rice stems. **Cakmac (2005)** indicated that high potassium contents in rice tissues help the plant to withstand the biotic and abiotic stresses.

3. Potassium, silica and nitrogen contents in stems of Giza 178 rice cultivar

3.1. Potassium content

Results of analysis of nutrient uptake in stems after nitrogen-potassium application are presented in Table (**10**). Nitrogen fertilization significantly increased potassium contents in stems at harvest in both seasons. Values of K were 1.55 and 1.54 % in plots fertilized with 92 kg N/fed, and 1.53 and 1.57% in plots fertilized with 69 kg N/fed., in the first and second seasons, respectively. The lowest K (0.71 and 0.85%) was obtained at 23 kg N. Thus, application of nitrogen as recommended dose results in high accumulation of potassium in the plant stems compared to lower doses of nitrogen. **Radha Madhav *et al.* (1996)** reported that optimum applications of urea positively increased the absorption of NPK, particularly in the early stages of crop development, with implications in later phases.

The application of potassium at rates of 24 or 36 kg/fed., increased the uptake of K, ranging between 1.38 and 1.56%, while zero or 12 kg K/fed., resulted in lower K uptake ranging between 0.98 and 1.10%. As for the effect of interaction between nitrogen and potassium on K uptake in stems, data in Figure 1A show that the highest K uptake occurred in plants fertilized with 69 or 92 kg N/fed., combined with 24 or 36 kg K/fed in both seasons. This is in agreement with the **Shrestha, *et al.* (2020)**, who reported that interactions between plant nutrients can produce synergistic effect which enhances the efficiency of nutrient use. They added that the uptake of the nutrients depends on the interactions of the individual nutrient.

3.2. Silica content

Higher nitrogen doses (69 or 92 kg N/fed) resulted in high significant different values of silica content in Giza 178 cultivar rice stems, compared with the lowest dose (23 kg N/fed). At 69 or 92 kg N/fed, silica contents in stems ranged between 2.78 and 3.08 % in both seasons of study. At 46 kg N/fed., the stem silica content was 2.05 % in each seaso**n**.

The same trend was detected with different application of potassium fertilizer. Higher silica contents (2.72 - 2.48 %) were obtained with 24 or 36 kg K/fed, while lower silica contents (2.05-2.30%) were detected with zero or 12 kg K/fed. **Farago, (1994)** demonstrated that a nutrient can reduce the absorption of another nutrient known as antagonism, while, uptake can be mutually enhanced – this interaction is called synergism**.**

The interaction between nitrogen and potassium (Figure 1 B), high significantly affected the contents of silica in rice stems. The greatest values of rice silica contents, ranging between 3.11 and 3.71%, were obtained with 69 or 92 kg N/fed, combined with 24 or 36 kg K/fed. On the other hand, the lowest silica contents in rice stems were obtained with the lower doses of nitrogen combined with the lower doses of potassium. **Zaman *et al.* (2015)** indicated that application of potassium along with nitrogen fertilization increased silica concentration in rice stems. Si itself, is not considered an important nutrient for the plants, but the advantage is the increases in cell wall thickness below the cuticle, which enhances mechanical resistance against the penetration of insect pests and fung**i**.

3.3. Nitrogen content

Different levels of nitrogen or potassium fertilizers induced highly significant differences in nitrogen content in stems of Giza 178 rice cultivar. The higher values of nitrogen content were obtained with 69 or 92 kg N/fed, and with 24 or 36 kg K/fed, with values ranging between 0.65 and 0.68% in case of nitrogen, and between 0.59 and 0.62% in case of potassium, in 2021 and 2022 rice seasons. The lower doses; 46 kg N/fed and 12 kg K/fed induced lower contents of nitrogen in rice stems. **Zaman *et al.* (2015)** noticed that increase in nitrogen concentration by application of higher doses of potassium may show the synergistic effect of potassium fertilization for nitrogen uptake by rice plants.

The interaction between nitrogen and potassium (Figure 1C), enhanced the nitrogen content in rice stems, with values ranging between 0.63 and 0.69 % due to the combinations of 24 or 36 kg K/fed and 69 or 92 kg N/fed. The lower doses (12 kg K combined with 46 kg N/fed) resulted in lower values; 0.53-0.57% N in rice stems. The higher nitrogen stem content could be attributed to the positive effect of nitrogen in some important physiological processes. Several researchers have reported an increase in nitrogen concentration in rice plant tissues due to nitrogen fertilization **(Metwally *et al*. 2011 and Zheng *et al.* 2021).**

Table 10. Effect of nitrogen, potassium fertilizers levels and their interaction on K, Si and N percentage in stem of Giza 178 rice cultivar.

Main effect and interaction	K % in stem		Si % n stem		N % in stem	
	2021	2022	2021	2022	2021	2022
N level (kg/fed)						
23	0.71 c	0.85 c	1.94 d	1.89 c	0.45 d	0.42 d
46	1.06 b	1.05 b	2.05 c	2.05 b	0.53 c	0.50 c
69	1.53 a	1.57 a	3.08 a	2.98 a	0.65 b	0.61 b
92	1.55 a	1.54 a	2.78 b	3.01 a	0.68 a	0.66 a
F test	**	**	**	**	**	**
K level (kg/fed)						
0	0.98 c	0.98 d	2.07 c	2.05 d	0.52 d	0.50 d
12	1.08 b	1.10 c	2.28 b	2.30 c	0.56 c	0.53 c
24	1.41 a	1.38 b	2.78 a	2.73 b	0.60 b	0.57 b
36	1.39 a	1.56 a	2.72 a	2.84 a	0.62 a	0.59 a
F test	**	**	**	**	**	**
Inter. N X K	**	**	**	**	**	**

Means within a column followed by the same letter do not differ significantly (*P* < 0.05) according to Duncan's Multiple Range Test.

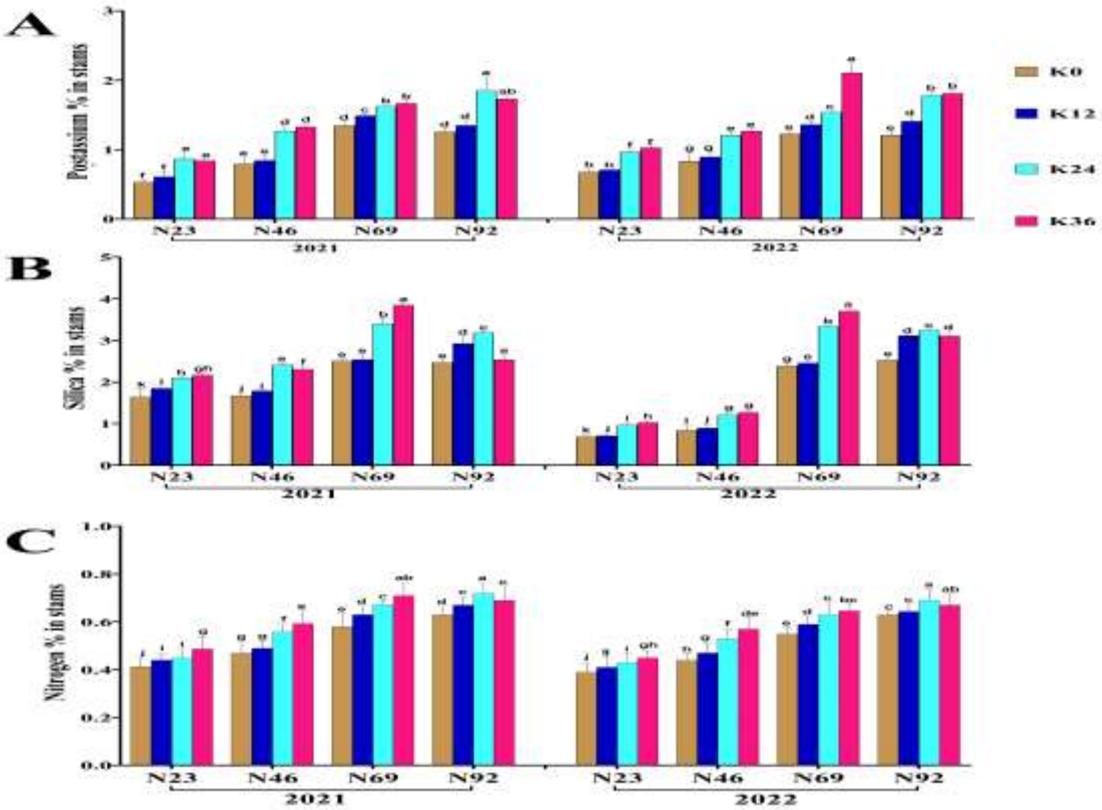

Fig. 1. Uptake of Potassium (A), Silica (B), and Nitrogen (C) in stem as influenced by A X C interaction, of Giza 178 rice cultivar.

4. Conclusion

The combination of nitrogen (69 kg N|fed) and potassium (24 or 36 kg|fed) performed the highest rice yield and yield attributes. Meanwhile, this combination reduced rice stem borer infestation in the check susceptible variety (Giza 178). Application of potassium with the recommended doses of nitrogen led to high uptake of both elements in rice stems. This is due the synergistic effect of nitrogen and potassium. In addition, potassium fertilization enhanced silica contents in rice stems leading to less insect infestation.

5. Conflicts of interest

The authors declare that they have no competing in-terests.

6. Formatting of funding sources

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