Response of Grain Yield of Some Maize Lines Grown in Calcareous Soil to Potassium Fertilization

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ABSTRACT

Three successive field experiments were conducted, during summer seasons of 2003, 2004 and 2005 at Nubaria Agriculture Research Station to study the effect of potassium fertilization on grain yield of five maize (Zea mays L.) lines grown in calcareous soil. Four rates of potassium, as potassium sulphate fertilizer, (0.0, 0.0571, 0.1140 and 0.1713 Mg K_2O ha^{-1}), and five maize lines: Sd.7, Gz.602, Gz.612, Gz.628 and Gm.2 were used. Data were recorded for grain yield (Mg ha^{-1}). Five polynomial quadratic equations were used to express the relation between grain yield of maize lines and potassium rates.

The following results were obtained:

- *Highly significant differences of grain yield were observed for years, potassium rates (K), maize lines and their interactions.*
- *Overall mean of grain yield increased from 2.71 (no K_2O) to 3.59 Mg ha^{-1} (0.1713 Mg K_2O ha^{-1}). The highest grain yield was obtained from Gz.602 line (3.98) followed by Sd.7 (3.47 Mg ha^{-1}), while the lowest yield was obtained from Gm.2 (2.34 Mg ha^{-1}).*
- *The maximum rates of potassium (X_{max}) ranged from 2.745 to 6.390 units of K_2O ha^{-1} (one unit of K_2O = 0.0571 Mg K_2O ha^{-1}). The highest value belonged to Gz.612 and the lowest value belonged to Gz.628. The optimum rates of potassium (X_{opt}) ranged from 2.734 to 5.555 units of K_2O ha^{-1} with an average 3.758, the lowest value belonged to Gz.628 and the highest value belonged to Gz.612.*
- *The values of Y_{max} for potassium fertilizer ranged from 2.676 to 4.415 Mg ha^{-1} with an average 3.272 Mg ha^{-1}, while the lowest value of maximum yield belonged to Gm.2 and the greatest value of (Y_{max}) belonged to Gz.602.*
- *The optimum grain yield of maize lines ranged from 2.665 to 4.410 Mg ha^{-1} with an average 3.713 Mg ha^{-1}, the highest value of Y_{opt} belonged to Gz.602 and lowest values belonged to Gm.2.*
- *The economic return values for the studied lines ranged between 3306.70 and 5680.30 EP ha^{-1} (Egyptian pound / hectare), with an average 4535.20 EP ha^{-1}, the highest value of return belonged to Gz.612 and the lowest value belonged to Gm.2.*
- *The net return values obtained from the studied lines ranged from 2578.11 to 4357.65 EP ha^{-1}, with an average 3637.23 EP ha^{-1}, while the lowest value belonged to Gm.2 and the highest value belonged to Gz.612.*
- *The returns per each 1 EP for the applied optimum rate of K_2O, ranged from 3.17 to 5.93 EP / 1 EP, with an average 4.34 EP. The lowest value belonged to Sd.7 and the highest value belonged to Gz.602.*

Key words: Maize lines, Optimum potassium fertilization, Optimum grain yield, Net return.

INTRODUCTION

Maize is one of the most important cereal crops in Egypt. Maize productively had increased from 3.8 tons ha^{-1} in 1980 to 8.72 tons ha^{-1} in 2004 (7th annual maize workshop, 2005). Such increase in productivity has been realized as a result of various factors i.e., release of high yielding hybrids resistant to pests and desirable agronomic characters, development of an appropriate package of recommended agronomic practices to attain maximum yield and availability of production inputs such as hybrid seed and fertilizers.

In 2004 growing season, the total national production of maize reached about 5.87 million tons resulted from an area of 1.68 million faddans (707.28 hectars). The annual national demand of maize is about 8.5 million tons which is more than the total production by about 3 million tons which is imported annually (7th annual maize workshop, 2005). Recently, National Maize Research Program (NMRP) has an optimistic plan to increase the national production of maize through four axes: *(1)* increasing yellow maize area especially in new lands such as Nubaria, Toshka and El-Ewinat, *(2)* increasing production of the breeder and foundation seeds of the commercial hybrids, *(3)* conducting numerous demonstration fields at the destrict level in different governorates across Egypt to acquaint farmers and extension staff with new yellow hybrids, and *(4)* planning a suitable marketing policy by determining a profitable high price to encourage farmers to grow yellow maize. It is known that inbred lines has low yield especially when grown in new lands. Therefore, to increase yield of inbred lines, the balanced recommended dose of fertilizers must be added.

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Organic matter, micronutrients and macronutrients at Nubaria soil are low especially exchangeable potassium (less than 120 mg kg^{-1}). More K at the surface soil is likely related to greater amounts of organic matter and a corresponding higher CEC (Johnson *et al.*, 2003). Potassium fertilization was associated with higher corn grain yields only in fields that had K soil-test available more than 120 mg kg^{-1} (Vyn and Janovicek, 2001). Potassium increased yields in several soils when K was banded (Mallarino *et al.*, 1999). Christians *et al.* (1981) observed that N x K interactions were more K was needed as N fertilization rates increased.

Plants growing on calcareous media commonly exhibit P and micronutrient deficiencies (Carrow *et al.*, 2001) because the alkaline pH of this soil renders these nutrients unavailable. Nutrient levels change rapidly because of the low cation exchange capacity (CEC) and high leaching potential of these media. Adequate K nutrition for corn is not only dependent on the available K concentrations in the bulk soil, but also on the availability of K in soil volumes where roots are actively growing during periods of rapid uptake (Vyn and Jànovicek, 2001). Any deficiencies in K availability in soil volumes that are actively exploited by corn roots during the rapid dry matter accumulation phase of corn growth before pollination can result in inadequate K nutritional status and may result in reduced yields (Heckman and Kamprath, 1992). Potassium fertilization increased grain yields slightly in several soils that tested optimum or higher in K_{ST} (Bordoli and Mallarino, 1998).

The objectives of this study were to: (*I*) evaluate the effect of potassium application on grain yield, and (*ii*) investigate the response of five maize commercial lines to potassium application in calcareous soil.

MATERIALS AND METHODS

This study was carried out in summer seasons of 2003, 2004 and 2005 to evaluate the effect of potassium application on grain yield and investigate the response of maize to potassium application in calcareous soil at five commercial maize lines (*Zea mays* L.) under four potassium levels at Nubaria Agric. Res. Station, Northwest of Egyptian Nile Delta.

A split-plot design with four replicates was used with potassium rates in main-plot and lines in sub-plot. Plot size was two rows; five meters long with 70 cm apart and 20 cm between hills. Potassium was added in the form of potassium sulphate fertilizer (48% K_2O) at four rates K_0, K_1, K_2, and K_3 (zero, 0.0571, 0. 1142 and 0.1713 Mg K_2O ha^{-1}) in two equal doses with the recommended doses of nitrogen. All the other cultivation practices were carried out as a commonly followed in Nubaria region. Data were recorded for ears weight / plot. The total shelled grain weight / plot was adjusted to 15.5% grain moisture content then converted to ton/hectare (Mg ha^{-1}).

The main physical and chemical characteristics of the soil of the experimental site (calciorthids) were determined according to the methods described by Page *et al.*, (1982) and presented in Table (1). The soil of Nubaria Agriculture Research Station is calcareous and is calciorthids.

Statistical analysis was performed according to Steel and Torrei (1980), by using ANOVA at SAS software (SAS software Rel. 6.12, 1997). Year effects were considered random, while potassium levels and maize lines were fixed effects in the analysis of variance. Tests for homogeneity of error variances were carried out according to Snedecor and Cochran (1981). Homogeneity differences between the errors variances

Table 1. The main chemical and physical characteristics of the experimental soil at Nubaria Agriculture Research Station.

Characters	Value
Soil pH *	8.2
E.C. dS m^{-1} **	2.44
Water soluble cations meq / l:	
Ca^{2+}	11.45
Mg^{2+}	8.19
K^+	1.19
Na^+	3.52
Water soluble anions meq / l:	
CO_3^{2-}	0.0
HCO_3^-	5.0
SO_4^{2-}	6.3
Cl^-	13.0
$CaCO_3$ %	27.4
Organic matter %	0.4
K_2SO_4-extrs field N, µg / g soil	20.7
$NaHCO_3$ – ext. P, µg / g soil	18.8
NH_4-OAc extract-K mg kg^{-1}	116.0
Mechanical analysis:	
Sand %	64.6
Silt %	12.5
Clay %	22.9
Soil texture	Sandy clay loam

* measured in 1:2.5 soil suspension.

** measured in water extracted of saturated soil paste of the three years were detected. Therefore, combined analysis over years was done, as a split-split plot design,according to expected mean square which presented in Table (2).

Definition and methods of calculation:

1- The polynomial quadratic equation:

$$Y = B_0 + B_1X + B_2X^2$$

Where; the term "Y" stands for the obtainable yield of lines when rates of potassium (X) are applied. The value of B_0 represents the intercept, or the amount of "Y" when X=0.0. The first slope "B_1" is termed the rectilinear slope or coefficient and "B_2" is the curvilinear or quadratic coefficient. The values of "B_0" and "B_1" are of the same significance as in the rectilinear equation. The term "B_2" expresses the rate of plant response in the upper curved part of the response curve. Mostly in plant response to fertilization, this term is negative indicating the tendency of the response decrease. The polynomial quadratic equations were calculated using the least squares method.

2- Maximum rates of potassium:

The maximum rates for potassium were calculated using the following relationship:

$$X_{max.} = -\frac{B_1}{2B_2}; \text{ (Balba, 1961).}$$

3- Optimum rates of potassium:

The optimum rates of potassium fertilizer application at each potassium incremental addition can be calculated by differentiating dy/dx and equating with the ratio potassium fertilizer and crop prices:

$$X_{opt.} = \frac{dy}{dx} = \frac{price\ of\ fertilizer\ unit}{price\ of\ maize\ crop\ unit}$$

4- Maximum grain yield of lines:

The maximum yield for potassium fertilization were calculated using the following relationship:

$$Y_{max.} = B_0 - [(B_1^2)/4B_2];$$ (Capurro and Voss, 1981).

5- Optimum grain yield of lines:

By substituting for ($X_{opt.}$) at each experimental treatment in the corresponding polynomial quadratic equation, the obtainable yield (optimum yield) of lines were calculated.

RESULTS AND DISCUSSION

Response of grain yield to potassium fertilization:

Highly significant differences of grain yield were observed for years, potassium rates, maize lines and their interactions except K x maize line (Table 2).

Significantly response of grain yield to potassium fertilization was observed for the studied lines (Tables 2 and 3). Overall mean of grain yield, over maize lines, was increased from 2.71 (no potassium applied) to 3.59 Mg ha^{-1} (K_3 = 0.1713 Mg K_2O ha^{-1}). Significantly, gradual increases of grain yield were detected with increasing potassium levels. The highest grain yield was observed for Giza-602 line (3.98 Mg ha^{-1}) followed by Sids-7 (3.47 Mg ha^{-1}), while the lowest line was Gemmiza-2 (2.34 Mg ha^{-1}). The other studied lines

Table 2. Expected mean square and mean square for grain yield of four potassium levels and five maize lines at Nubaria during 2003, 2004 and 2005.

S.O.V.	df	Grain yield	
		Expected mean square	Mean square
Year (Yr)	2	$\sigma^2_a + 96\,\sigma^2_Y$	47.70 **
Error (a)	9	σ^2_a	0.19
Pot. rate (K)	3	$\sigma^2_b + 24\,\sigma^2_{YP} + 72\,K^2_p$	10.20 **
Yr x K	6	$\sigma^2_b + 24\,\sigma^2_{YP}$	0.30 **
Error (b)	27	σ^2_b	0.06
Lines (Lin)	4	$\sigma^2_c + 16\,\sigma^2_{YL} + 48\,K^2_L$	18.86 **
Yr x Lin	8	$\sigma^2_c + 16\,\sigma^2_{YL}$	2.10 **
K x Lin	12	$\sigma^2_c + 4\,\sigma^2_{YPL} + 12\,K^2_{pL}$	0.09
Yr x K x Lin	24	$\sigma^2_c + 4\,\sigma^2_{YPL}$	0.24 **
Error (c)	144	σ^2_c	0.04
C.V.			6.2

** Highly significant differences at 0.01 level of probability.

Table 3. Actual and predicted grain yield of five maize lines as affected by K application rates during 2003, 2004 and 2005.

Maize lines		Grain yield (Mg ha^{-1})				
		K_0	K_1	K_2	K_3	Mean
Sids-7	actual	3.030	3.260	3.760	3.840	3.47
	predicted	2.995	3.363	3.655	3.871	3.30
Giza-602	actual	3.440	3.830	4.200	4.460	3.98
	predicted	3.320	3.917	4.282	4.415	3.99
Giza-612	actual	2.400	2.540	3.240	3.240	2.86
	predicted	2.339	2.728	3.051	3.308	2.86
Giza-628	actual	2.750	3.310	3.680	3.770	3.38
	predicted	2.745	3.323	3.667	3.777	3.38
Gemmiza-2	actual	1.920	2.210	2.600	2.640	2.34
	predicted	1.896	2.279	2.534	2.661	2.34
Mean	actual	2.71	3.03	3.49	3.59	3.21
	predicted	2.86	3.12	3.44	3.41	3.21
LSD $_{0.05}$ (K)		0.24				
LSD $_{0.05}$ (lines)		0.68				

where: K_0 = 0.00 (no K applied), K_1 = 0.0571 Mg K_2O ha^{-1}, K_2 = 0. 1142 Mg K_2O ha^{-1}, and K_1 = 0.1713 Mg K_2O ha^{-1}.

yielded 3.38 and 2.86 Mg ha^{-1} for Giza-628 and Giza-612, respectively.

Out of six, four lines (Sids-7, Giza-612, Giza-628 and Gemmiza-2) didn't differ significantly when potassium level exceeded K_3 = 0. 1142 Mg K_2O ha^{-1}, whereas the other line (Giza-602) was responded significantly to 0.1713 Mg K_2O ha^{-1} (Table 3). Therefore, the rate of potassium fertilization application should be at least 0. 1142 Mg K_2O ha^{-1} (48 kg K_2O fad^{-1}) for efficient maize production at Nubaria region. Response of grain yield to potassium fertilization may be due to the low level of potassium at Nubaria soil. These results agree with those reported by Christians *et al.* (1981), Bordoli and Mallarino (1998), Mallarino *et al.* (1999) and Vyn and Janovick (2001).

Establishing quantitative relations:

The polynomial quadratic equations were established to express the maize lines grain yield response to potassium fertilizer application. Equations No. 1 – 5 are presented in Table (4). The actual and predicted grain yield of the studied lines obtained from such equations is shown in Table (3). The predicted values of grain yield for the studied lines were approximate close and didn't significantly differ from the actual values for each potassium rate.

Maximum and optimum potassium rates:

The maximum potassium rates were calculated using the following relationship; $X_{max.} = (- B_1 / 2B_2)$, (Balba, 1961). The values of X_{max} for potassium were calculated using values of equations 1 – 5 and presented in Table (5). The results showed that the maximum rates of potassium ranged from 2.745 to 6.390 units of K_2O ha^{-1} (one unit of K_2O=0.0571 Mg K_2O ha^{-1}), with an average

Table 4. Polynomial quadratic equations expressing yield of five maize lines and rates of potassium application.

Line	Polynomial quadratic equations	Equ. no.
Sids-7	$Y = 2.995 + 0.406\ X - 0.038\ X^2$	1
Giza-602	$Y = 3.320 + 0.713\ X - 0.116\ X^2$	2
Giza-612	$Y = 2.339 + 0.422\ X - 0.033\ X^2$	3
Giza-628	$Y = 2.745 + 0.695\ X - 0.117\ X^2$	4
Gemmiza-2	$Y = 1.896 + 0.447\ X - 0.064\ X^2$	5

4.207 units of K_2O ha^{-1}. The highest value belonged to Giza-612 and the lowest of X_{max} belonged to Giza-628.

The optimum rates of potassium fertilizer were calculated by differentiating "Y" in the polynomial equations 1 – 5 with regard to "X" (dy / dx) and equating with the ratio of the fertilizer unit price and the price of the maize lines grain yield unit (Mg) which presented in Table (5). The values of X_{opt} ranged from 2:734 to 5.555 units of K_2O ha^{-1}, with an average 3.758. The lowest value belonged to Gz.628 while the highest value belonged to Giza-612.

The maximum yield for each studied maize line was calculated using the following relationship; $Y_{max} = B_0 - [(B_1^2) / 4B_2]$, (Cappurro and Vass, 1981). The values of Y_{max} for potassium fertilizer were calculated using values equations 1 – 5 which presented in Table (4). The results showed that the maximum actual grain yield of the studied lines ranged from 2.676 to 4.415, with an average 3.727 Mg ha^{-1} (Table 5). The lowest value of the maximum grain yield belonged to Gm.2 and the highest value belonged to Gz.602.

Maximum and optimum grain yield of lines:

Table 5. Maximum (Y max) and optimum (Y opt) yields, values of maximum, optimum rates of potassium and returns of maize grain.

Lines	X max. unit ha^{-1}	Y max. Mg ha^{-1}	X opt. unit ha^{-1}	Y opt. Mg ha^{-1}	Maize price EP $unit^{-1}$	Fert. price EP $unit^{-1}$
Sids-7	5.340	4.079	4.610	4.060	4300.00	238.10
Giza-602	3.070	4.415	2.835	4.410	4300.00	238.10
Giza-612	6.390	3.688	5.555	3.660	4300.00	238.10
Giza-628	2.745	3.777	2.734	3.770	4300.00	238.10
Gemmiza-2	3.490	2.676	3.060	2.665	4300.00	238.10
Lines	**Total value of yield EP ha^{-1}**	**Total value of yield at control EP ha^{-1}**	**Return EP ha^{-1}**	**Fert. cost EP ha^{-1}**	**Net return EP ha^{-1}**	**EP / one EP**
Sids-7	17458.00	12878.50	4579.50	1097.64	3481.86	3.17
Giza-602	18963.00	14276.00	4687.00	675.01	4011.99	5.93
Giza-612	15738.00	10057.70	5680.30	1322.65	4357.65	3.29
Giza-628	16211.00	11803.50	4407.50	650.96	3756.54	5.77
Gemmiza-2	11459.50	8152.80	3306.70	728.59	2578.11	3.54

The values of optimum grain yield (Y_{opt}) for potassium fertilizer were calculated by substitution of (X) by the corresponding values of optimum rate of application (X_{opt}) in equations 1 – 5 which presented in Table (4). The optimum grain yield of the studied lines are and presented in Table (5). The results showed that the optimum grain yield of lines ranged from 2.665 to 4.410, with an average 3.713 Mg ha^{-1}. The highest value of the optimum grain yield belonged to Giza-602 while the lowest value belonged to Gemmiza-2.

The economic returns from applied optimum rate of potassium fertilizer:

The returns per hectare as a result of optimum rate of K_2O fertilizer application to the studied maize lines are presented in Table (5). The return values for the studied lines ranged from 3306.70 to 5680.30 EP ha^{-1} (Egyptian pound / hectare), with an average of 4532.20 EP ha^{-1}. The highest value of return belonged to Giza-612 and the lowest value belonged to Gemmiza-2 (Table 5). The net return values of the studied lines ranged from 2578.11 to 4357.65, with an average 3637.23 EP ha^{-1}. The lowest value of net return belonged to Gemmiza-2, while the highest value belonged to Giza-612. The return per 1 EP spent for the applied optimum potassium rate ranged from 3.17 to 5.93 EP/1 EP, with an average 4.34. The lowest value belonged to Sids-7 while the highest value belonged to Giza-602.

The present study has demonstrated the importance of optimizing potassium fertilization for maize lines grown in calcareous soil; to increase maize grain yield.

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الملخص العربي

استجابة محصول الحبوب لبعض سلالات الذره الشاميه المزروعة فى الأراضي الجيريه للتسميد البوتاسي

جمال محمد الشبيني، أحمد عبدالمنعم حبليزه

- زرعت ثلاثة تجارب حقليه خلال الموسم الصيفي لمواسم ٢٠٠٣ ، ٢٠٠٤ و٢٠٠٥ بمحطة البحوث الزراعيه بالنوباريه بهدف دراسة تأثير إضافة السماد البوتاسي على محصول الحبوب على ٥ سلالات تجاريه من الذره الشاميه. استخدم ٤ مستويات من التسميد البوتاسي شملت صفر، ٢٤ ، ٤٨ و٧٢ كجم بو٢أ / فدان. تم زراعة ٥ سلالات ذره شاميه تجاريه هي: سدس-٧، جيزه-٦٠٢، جيزه-٦١٢ ، جيزه-٦٢٨ وجميزه-٢. تم تسجيل البيانات لصفة محصول الحبوب (طن / هكتار). حسبت خمسة معادلات من الدرجة الثانية للتعبير عن العلاقة بين إنتاجية سلالات الذره الشامية ومعدلات السماد البوتاسي.
- وقد أوضحت النتائج وجود فروق عالية المعنويه لصفات محصول الحبوب راجعة الى السنوات، مستويات البوتاسيم والسلالات تحت الدراسه.
- زاد محصول الحبوب كمتوسط للسلالات مجتمعه من ٢,٧١ (بدون تسميد) حتى ٣,٥٩ طن/هكتار (٧٢ كجم بو٢أ / فدان). أعطت السلاله جيزه-٦٠٢ أعلى محصول للحبوب (٣,٩٨) تليها السلاله سدس-٧ (٣,٤٧ طن/هكتار)، بينما أعطت السلاله جميزه-٢ أقل محصول للحبوب (٢,٣٤ طن/هكتار).
- تراوحت قيمة أقصى معدل إضافة من سماد البوتاسوم بين ٢,٧٤٥ و٦,٣٩٠ وحدة بو٢أ / هكتار (الوحده من بو٢أ = ٠,٠٥٧١ طن / هكتار) وكانت أكبر قيمة للسلاله جيزه-٦١٢ بينما كانت أقل قيمة للسلاله جيزه-٦٢٨. تراوحت قيمة المعدل المثالى من سماد البوتاسيوم من ٢,٧٣٤ الى ٥,٥٥٥ وحدة بو٢أ / هكتار بمتوسط قدره ٣,٧٥٨ وكانت أقل قيمة للسلاله جيزه-٦٢٨ بينما كانت أعلى قيمة للسلاله جيزه-٦١٢.
- تراوحت قيمة أقصى إنتاجية للسلالات تحت الدراسة من ٢,٦٧٦ الى ٤,٤١٥ بمتوسط قدره ٣,٢٧٢ طن / هكتار وكانت أقل قيمة للسلاله جميزه-٢ بينما كانت أكبر القيم للسلاله جيزه-٦٠٢. تراوحت قيمة محصول الحبوب المثالى بين ٢,٦٦٥ و٤,٤١٠ طن / هكتار بمتوسط ٣,٧١٣ طن / هكتار وكانت أعلى القيم للسلاله جيزه-٦٠٢ بينما كانت أقل القية للسلاله جميزه-٢.
- تراوحت قيمة العائد النقدى من ٣٣٠٦,٧ الى ٥٦٨٠,٣ بمتوسط قدره ٤٥٣٥,٢ جنيه / هكتار وحققت السلاله جيزه-٦١٢ أعلى قيمة للعائد النقدى بينما أعطت السلاله جميزه-٢ أقل قيمة.
- تراوح صافى العائد النقدى للسلالات تحت الدراسة من ٢٥٧٨,١١ الى ٤٣٥٧,٦٥ بمتوسط قدره ٣٦٣٧,٢٣ جنيه/ هكتار، وأعطت السلاله جميزه-٢ أقل صافى عائد نقدى بينما أعطت السلاله جيزه-٦١٢ أعلى صافى عائد.
- تراوحت قيمة عائد الجنيه المستثمر فى التسميد بالمعدل المثالى من السماد البوتاسى من ٣,١٧ الى ٥,٩٣ بمتوسط قدره ٤,٣٤ جنيه/ جنيه وأعطت السلاله سدس-٧ أقل قيمة بينما أعطت السلاله جيزه-٦٠٢ أعلى قيمة عائد.