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Influence of Genotypes and Potassium Application Rates on Yield and Potassium Use Efficiency of Potato

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Abstract: Two year experiment (1999-2001) was conducted at Tal Amara Research Station in the Bekaa Valley of Lebanon to evaluate the influence of progressive application of Potassium fertilizer on yield, tuber quality, potassium uptake and potassium use efficiency (KUE) of 4 potato (*Solanum tuberosum* L.) genotypes. Four levels of potassium [0 (K_0), 96 (K_{96}), 192 (K_{192}) and 288 (K_{288}) kg K_2O ha^{-1}) and 4 genotypes (Spunta and Derby in 1999; Shepody and Umatilla in 2001) were used in a split-plot design. Medium and large grade tubers and aggregate tuber yield increased quadratically with increasing K application rates up to 192 kg K_2O ha^{-1}, reaching a plateau thereafter, indicating the luxury consumption of the nutrient at 288 kg K_2O ha^{-1}. When averaged over year and K application rates, Spunta, Derby and Umatilla followed by Shepody exhibited the highest aggregate yield. Tuber K uptake increased in all genotypes with increasing K application rates. A genetic variation in tuber potassium uptake was recorded, with the highest values observed on Derby and Umatilla, followed by Shepody and finally on Spunta. When averaged over genotypes, K_{192} treatment resulted in 19 and 61% higher KUE value than those recorded by K_{92} and K_{288} treatments, respectively. Finally, when averaged over K rates, the KUE of Spunta was higher by 2, 36 and 11% than those observed on Derby, Shepody and Umatilla.

Key words: Aggregate tuber yield, genetic variation, potassium uptake, *Solanum tuberosum* L., tuber quality

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the major crops contributing to the worlds food requirement, ranking fourth in production volume after rice, wheat and maize because it is a rich source of starch and having protein of a high biological value (Eppendorfer and Eggum, 1994). In Lebanon, potato occupies a 19,700 ha area with a total production of 460,000 t, but average yield is only 23 t ha^{-1}, which is much below the crops potential productivity. The expected reason for such a low yield seems to be the imbalance in nutrients applied for the agricultural production of this crop.

Farmers usually diagnose and correct the deficiencies of nitrogen (N) and phosphorus (P), but often neglect the effect of deficiencies of other essential macronutrients such as potassium (K), which will affect the response of crops to N and P. In addition to N and P, K requirement of potato is also very high in view of the luxuriant vegetative growth of the crop and the removal of the large quantities of the soil nutrients due to its poorly developed shallow root system and high rate of dry matter production in a short duration (Perrenoud, 1993; Singh and Trehan, 1998; Kumar *et al*., 2007). On an average, the potato crop, yielding about 37 ha^{-1} removes about 196 K_2O ha^{-1} (Perrenoud, 1993). Since biomass and bulking rate of potato tubers are positively affected by synthesis and accumulation of starch, K plays a key role in this regard as it influences cell division, tuberous root initiation and thickening, photosynthesis-formation of carbohydrates, translocation of sugars, mineral nutrients and photosynthetic matter and it also influences enzyme activity (George *et al*., 2002; Byju and George, 2005). Hence, an optimum K level, along with optimum levels of N and P would, therefore, be required to exploit the full genetic potential of the crop and achieve an improved level of tuber yield and quality. The available amount of these elements is often insufficient in soils and must be supplied as fertilizers.

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Currently, the application of mineral fertilizers in modern agriculture is a common feature of crop production throughout the world. A serious problem we face nowadays is the relatively low efficiency of fertilizer use (Saurbeck and Helal, 1990). Low fertilizer utilization increases the potential hazards of environmental pollution. Therefore, the improvement of nutrient efficiency in crops is an important issue both for reducing cost in agricultural production and for protecting the environment.

Nutrient use efficiency has been defined by various researchers. According to Swaider *et al*. (1994) efficient use of nutrients is the relative ability of plants, to produce maximal amounts of dry matter for each increment of nutrient accumulated. Others also defined nutrient efficiency as plant yield (productivity) per unit of nutrient supply (Saurbeck and Helal, 1990).

It is important to identify the genotypes with higher Nutrient Use Efficiency (NUE) in particular potassium use efficiency (KUE) and to understand the mechanism of differences in response to fertilizer (i.e., potassium) application between genotypes.

Starting from the above considerations, the aim of this study is to observe the effect of four progressive levels of potassium on the performance of four commonly grown potato genotypes in terms of yield, tuber quality, potassium uptake and potassium use efficiency (KUE) and to identify the genotypes which are more efficient in K uptake and utilization efficiency.

MATERIALS AND METHODS

Experimental site and general conditions: The research took place during 1999 (experiment 1) and 2001 (experiment 2) at Tal Amara research station in the Bekaa valley of Lebanon (33°51′44′′N lat., 35°59′32′′E long., 905 m.a.s.l.). Tal Amara has a well-defined hot and dry season from May to October and a very cold one for the remainder of the year. Average seasonal rain is 592 mm, with 95% of the rain occurring between November and March. Table 1 shows the monthly climate data during the two growing seasons compared to the long-run means.

Table 1: Weather conditions prevailed during the experiments compared to the long-run data at Tal Amara

Time period	T_a (°C)	RH (%)	Rain (mm)	R_g (MJ/m²/day)	U_2 (km h^{-1})	E_o (mm)
1999						
July	23.9	43.9	0.0	29.1	10.8	425.1
August	25.0	42.9	0.0	25.8	8.6	358.6
September	21.3	45.7	0.0	22.8	9.3	279.0
October	19.0	50.3	35.5	13.8	11.4	250.4
2001						
July	23.8	41.3	0.0	25.9	10.8	344.0
August	23.5	50.7	0.0	24.0	9.6	264.2
September	21.5	51.1	4.1	20.2	9.5	209.6
October	18.5	50.0	16.0	14.2	10.9	240.4
Long run data (1954-2002)						
July	21.8	63.0	0.0	26.4	7.6	334.0
August	22.5	64.0	0.0	24.8	7.9	288.0
September	20.1	66.0	0.0	20.6	6.1	214.0
October	16.6	68.0	23.0	15.5	4.5	165.0

[a]T_a: Air temperature; RH: Relative humidity; R_g: Global radiation; U_2: Wind speed at 2 m height; E_o: Evaporation from pan class A

Soils of the experimental site were deep, non-calcareous, clay Eutric Cambisols with an average bulk density of 1.2 g cm^{-3}. Air dried soil samples were ground and sieved (2 mm) and analyzed at the Central Analytical Chemistry Laboratories in Tal Amara. The procedures for soil analysis were as follows: pH H_2O (1:5 w/v); organic matter and total N by Leco CNS-2000 dry combustion; available P by Olsen; available K by 1 M NH_4OAc percolation (pH 7.0) (Sparks, 1996). Soil chemical and physical properties were: available N content 45.5 g kg^{-1}, available P content 17.0 g kg^{-1} and available K content 11.5 g kg^{-1}, organic matter content 1.2% and pH 7.9. The measured field capacity (-0.33 bar) and permanent wilting point (-15 bar) averaged 29.5 and 16.0%, respectively by weight. Extractable plant water is estimated at 190 mm for 1 m rooting depth. Irrigation water, originating from a local well, had a good quality (pH of 7.5 and EC = 0.4 dS m^{-1}).

Treatments and management: In both years, the field experiment was set up in a split-plot design (main plot factor: potassium level; subplot-factor: genotype). The trial covered four levels of potassium [0 (K_0), 96 (K_{96}), 192 (K_{192}) and 288 (K_{288}) kg K_2O ha^{-1}) times 2 genotypes (Spunta and Derby in 1999; Shepody and Umatilla in 2001) treatments, with 5 replications. In both years, preplant fertilizer was broadcast (kg ha^{-1}; 17N -17P -17K) and incorporated into the soil. Potato genotypes were sown on 2 July 1999 and 4 July 2001. Each experimental unit consisted of 6 rows, 5 m in length, with 0.7 m row spacing, giving a theoretical plant population of 57, 142 plants ha^{-1}. In both years, a fertilizer dose of 144 kg N and 96 kg P_2O_5 ha^{-1} was applied in two splits after planting (38 Days after Planting, DAP) and at tuber initiation (61 DAP) uniformly to all the plots. Potassium was applied at tuber initiation with irrigation water.

In both years, the experiments were conducted under optimum irrigation conditions using line source drippers. Drip irrigation tape was installed on the soil surface at 10 cm distance from the plant row. The irrigation tape (T-tape; T-systems International, San Diego) had outlets for watering at 30 cm intervals and with a flow rate of 4 L h^{-1} per emitter. The potato plots were weeded manually at regular intervals as weeds may greatly affect the yield in root crops (Gurnah, 1985). The experiments were concluded on 30 October 1999 (120 DAP) and on 31 October 2001 (119 DAP).

Data collection: After the harvest, the tuber yield was grouped into three grades, namely large (>75 g), medium (25-75 g) and small (<25 g). The grade-wise and aggregate tuber yield were recorded. Tubers were dried in a forced-air oven at 80°C for 72 h and weighed to determine the tuber Dry Matter (DM). The tuber potassium concentration at four different stages (tuber initiation, tuber bulking, mature tubers and at harvest) was measured on dried samples, which were ground with a cyclone mill. Before determining K concentration by flame photometry, the samples were moist-ashed with H_2SO_4-H_2O_2 (George *et al*., 2002). The K uptake of tubers was calculated by multiplying K concentration by tuber DM.

The maximum requirement of K was determined for each genotype by fitting a quadratic equation computed between K application rates and aggregate tuber yield. Potassium use efficiency (KUE, Kg of tuber produced per kg of K_2O applied) of the potato genotypes were determined by subtracting the control (K_0) yield from the yield obtained at a particular K level and then dividing the outcome value by the quantity of the K fertilizer applied at that level (Janssen, 1998):

$$KUE = \frac{(Y_K - Y_0)}{K_R} \quad (1)$$

where, Y_K is yield as the particular K level, Y_0 is yield at K_0 level (control) and K_R is the particular K rate.

Statistical analysis: Analysis of variance of the data was calculated using the software package, SPSS 10 for Windows, 2001. In both experiments, orthogonal contrasts were used to compare potassium levels (Gomez and Gomez, 1983) on selected parameters. Regression analyses were conducted to identify relationships between aggregate tuber yield and K application rates.

RESULTS AND DISCUSSION

Tuber yield and yield components: In experiment 1 (1999), medium and large grade tubers and aggregate tuber yield were highly influenced by K application rates, but not by genotypes, with significant K application rates×genotypes interaction (Table 2). Moreover, in experiment 2 (2001) small, medium and large grade tubers and aggregate tuber yield were significantly affected by K application rates, genotypes, with significant K application rates×genotypes interaction (Table 3). In both years, tuber dry matter was significantly affected by K application rates but not by genotypes and by K application rates×genotypes interaction (Table 2, 3).

Irrespective of genotypes, medium and large grade tubers and aggregate tuber yield increased quadratically with increasing K application rates up to 192 kg K_2O ha^{-1}, reaching a plateau thereafter, indicating the luxury consumption of the nutrient at 288 kg K_2O ha^{-1} (Table 2, 3). Significant increase in tuber yield of potato as a result of K application is well documented (Cordova and Valverede, 2001; Singh *et al*., 2001; Tawfik, 2001; Umar and Moinuddin, 2001; Moinuddin *et al*., 2004, 2005). In fact, potato has a higher potassium requirement for optimum production as compared to cereals, pulses, oilseeds and other commercial crops and produces much more dry matter in short growth duration. It produces large amounts of starch due to K-mediated carbohydrate metabolism (Perrenoud, 1993; Singh and Trehan, 1998). Besides, it helps in efficient translocation of photoassimilates to the developing sinks/tubers (Beringer, 1978) and enabling the plants to utilize fully applied N and P fertilizers (Mengel and Kirkby, 1987). Thus, K helps the potato tubers to gain large size and heavier weight. This was evident in the current study, as we observed a progressive increase in aggregate tuber yield in addition to that in the yield of medium and large grade tubers as a result of increasing K application rates. Contrarily, the yield of small-grade tubers followed an opposite trend (Table 2, 3), since the ontrol treatment (K_0)

Table 2: Effects of genotypes and potassium application rates on grade-wise, aggregate tuber yield and tuber dry matter of potato plants grown in 1999

Genotypes	Potassium applied (kg K_2O ha^{-1})	Grade-wise tuber yield (t ha^{-1}) Small (<25 g)	Medium (25-75 g)	Large (>75 g)	Aggregate yield (t ha^{-1})	Tuber dry matter (%)
Spunta	0	5.0	21.0c	5.0c	31.0c	14.2
	96	4.9	25.0b	8.0b	37.9b	14.5
	192	4.6	29.6a	11.6a	45.8a	15.6
	288	4.2	29.4a	12.3a	45.9a	15.9
Derby	0	5.0	20.6c	5.0c	30.6c	13.9
	96	4.7	24.5b	8.1b	37.3b	14.3
	192	4.4	28.7a	11.7a	44.8a	15.7
	288	4.1	29.2a	12.4a	45.7a	16.2
Significance[a]						
Genotypes (G)		NS	NS	NS	NS	NS
Potassium (K)		L*	Q*	Q**	Q*	L*
G×K		NS	*	**	*	NS

[a] L: Linear, Q: Quadratic; NS, *, **Non-significant or significant at p≤0.05 and 0.01, respectively. Values with different letter(s) are significantly different

Table 3: Effects of genotypes and potassium application rates on grade-wise, aggregate tuber yield and tuber dry matter of potato plants grown in 2001

Genotypes	Potassium applied (kg K_2O ha^{-1})	Grade-wise tuber yield (t ha^{-1}) Small (<25 g)	Medium (25-75 g)	Large (>75 g)	Aggregate yield (t ha^{-1})	Tuber dry matter (%)
Shepody	0	4.0c	6.0e	2.0e	12.0f	20.1
	96	2.9d	10.1d	4.2de	17.2e	21.9
	192	2.8d	14.8c	6.4d	24.0d	22.7
	288	2.9d	12.4cd	5.5d	20.8e	22.8
Umatilla	0	10.0a	12.0cd	8.0c	30.0c	19.7
	96	8.0b	17.0b	10.0b	35.0b	20.1
	192	7.8b	22.2a	15.5a	45.5a	20.5
	288	7.8b	21.2a	14.7a	43.7a	21.1
Significance[a]						
Genotypes (G)		***	**	**	***	NS
Potassium (K)		Q*	Q*	Q*	Q*	L*
G × K		**	**	**	**	NS

[a]L: Linear, Q: Quadratic; NS, *, **, ***Non-significant or significant at $p \leq 0.05$, 0.01 and 0.001, respectively. Values with different letter(s) are significantly different

gave the highest tuber yield, which decreased linearly and quadratically (for experiments 1 and 2, respectively) by increasing K levels. This result indicates that small-sized tubers (<25 g) could be produced for potato seed production by applying comparatively lower doses of K along with the recommended N and P fertilizer dose. These results are consistent with the findings of Moinuddin *et al.* (2004, 2005), who showed an increase in tuber yield, large and medium grade tubers and a decrease in the yield of small grade with a progressive application of K fertilizer (from 0 to 225 kg K_2O ha^{-1}). In contrast, others have reported that an increase in K application rates, revealed an increase in the yield of small-grade (< 25 g) tubers and decrease in the two categories of medium grade tubers, weighing 51-75 g and 25-50 g, respectively (Singh *et al.*, 1997). Explanations for this disagreement could be that the yield trends of different grades are governed not only by the K application rates, but also by the genetic characters of the genotype (s) employed for the study, depending on how much K is utilized by a genotype with regard to different grades of tubers.

In fact, when averaged over year and K application rates, Spunta, Derby and Umatilla followed by Shepody expressed its yield potential maximally at various K rates in case of aggregate yield and the yield of large grade tubers (Table 2, 3). Regarding small and medium grade tubers, Shepody exhibited the lowest values in comparison to the others genotypes.

Potassium uptake and potassium use efficiency: Tuber potassium uptake was significantly affected by the development stage, K application rates and genotypes (Fig. 1). Among the four genotypes, the response pattern of potassium uptake to K rates showed the lowest K uptake at tuber initiation (66 days after sowing). After this period, K uptake increased during tuber bulking (80 d.a.s) and mature tuber (101 d.a.s.) to reach the maximum uptake at harvest (120 d.a.s.). Moreover, the tuber K uptake

Table 4: Potassium (K_2O) requirement for maximum tuber yield of potato genotypes as computed by quadratic relationship between potassium levels and aggregate tuber yield

Genotype	Quadratic equation[a]	Maximum K_2O requirement (kg K_2O ha^{-1})[b]	Corresponding tuber yield (t ha^{-1})
Spunta	$30.56+0.1079x-0.0002x^2$	271	45.1
Derby	$30.23+0.1003x-0.0002x^2$	251	42.8
Shepody	$11.42+0.1002x-0.0002x^2$	250	23.9
Umatilla	$29.11+0.1069x-0.0002x^2$	267	43.3

[a]Quadratic equation: $Y = a+bx+cx^2$. Where, Y: Tuber yield; x: K levels; a, b and c = known constants of the quadratic equation. [b]Maximum K_2O dose (kg ha^{-1}) = b/2c

increased in all genotypes with increasing K application rates. Increased recovery of K by tubers after progressive application of K fertilizer was also observed by Allison *et al.* (2001), who found that the increase in K taken up to be primarily due to increased tuber dry matter. Finally, when averaged over year and K application rates, a genetic variation in tuber potassium uptake was recorded in the two years field experiments, with the highest values observed on Derby and Umatilla, followed by Shepody and finally on Spunta. Similar studies on genotypic differences in nutrient uptake have been made by many researchers in different crops (Woodend and Glass, 1993; Swaider *et al.*, 1994; Yan *et al.*, 1995; Zhang *et al.*, 1999; Chen and Gabelman, 2000; George *et al.*, 2002).

Maximum K application rate (kg K_2O ha^{-1}) and the respective tuber yield were determined for each genotype, by fitting quadratic equations between K application rates and the aggregate tuber yield (Table 4). Among the genotypes, Spunta, followed by Umatilla, Derby and Shepody, proved to be the genotype, requiring the highest maximum K application rate. It is interesting to note that Derby and Shepody showed similar maximum K requirement (250 kg K_2O ha^{-1}), but with a substantial difference in maximum tuber yield (19 t ha^{-1}), indicating the considerable difference in K utilization efficiency of the 2 genotypes.

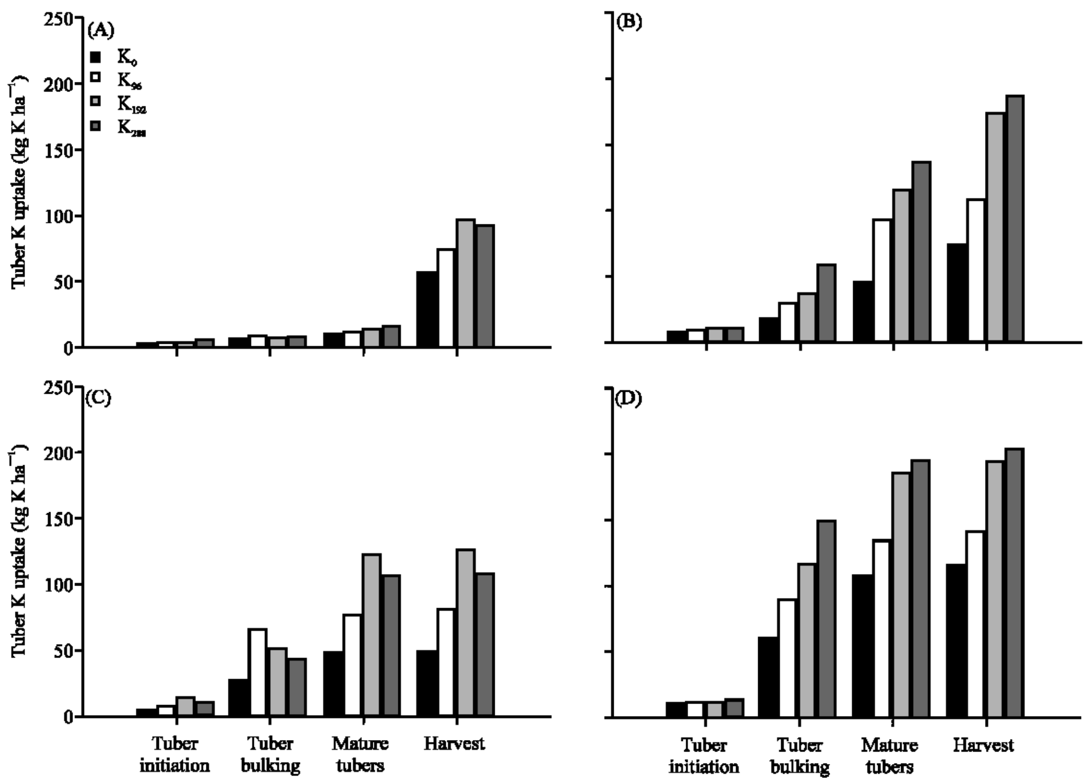

Fig. 1: Effect of potassium application rates on tuber potassium uptake recorded at different stages on Spunta (A) and Derby (B) in 1999 and on Shepody (C) and Umatilla (D) in 2001 growing seasons. LSD ($p = 0.05$) is presented as vertical line bar

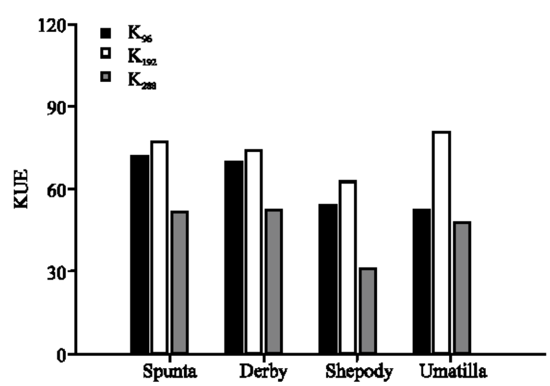

Fig. 2: Potassium use efficiency (KUE, kg of tuber yield per kg of K_2O applied) of potato genotypes grown in 1999 and 2001 as affected by potassium application rates. LSD ($p = 0.05$) is presented as vertical line bar

When averaged over genotypes, K_{192} resulted in 19 and 61% higher potassium use efficiency (KUE) value than those recorded by K_{92} and K_{288} treatments, respectively (Fig. 2). These results of KUE were similar with those reported by Moinuddin *et al.* (2004), when application of muriate of potash was increased from 75 to 225 kg K_2O ha^{-1}. Finally, when averaged over K rates, the KUE of Spunta was higher by 2, 36 and 11% than those observed on Derby, Shepody and Umatilla, respectively (Fig. 2).

CONCLUSION

To summarize, the progressive application of potassium fertilizer from 0 to 288 kg K_2O ha^{-1}, significantly affected the yield and yield components, tuber potassium uptake and potassium use efficiency of potato. Genotypic differences, with regard to these parameters, were also significant. Both the two years field experiments showed that medium and large grade tubers and aggregate tuber yield increased quadratically with increasing K application rates up to 192 kg K_2O ha^{-1}, reaching a plateau thereafter, showing luxury consumption of the nutrient at 288 kg K_2O ha^{-1}, or were decreased, indicating the detrimental effect of the over fertilization. Maximum KUE was associated with K_{192}, decreasing at both K levels: K_{98} and K_{288}. This indicates that K_{192} could be maximally utilized by all genotypes. Finally, among the genotypes, Spunta and Derby exhibited the highest crop performance in terms of yield parameters as well as KUE and interacted best with a K rate of 192 kg K_2O ha^{-1}.

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