Fertigation and Conventional Potassium Application to Field Grown Potato in Lebanon: Perspective to Enhance Efficiency

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ABSTRACT

In Lebanon, potato occupies a surface of 14,800 ha corresponding to 17% of the irrigated land. The Bekaa valley is the largest production area in the country, with more than 67% of total potato production located on prime land. This crop is generally fertilized by soil application and irrigated by sprinklers with rare implementation of drip systems. Spring and summer potatoes depend entirely on irrigation, with an average yield of 20-25 t/ha of fresh tubers.

In general, potato is cropped within a rotation consisting of wheat-potato-vegetable or legume rotation. For adequate growth, potato requires large amounts of potassium and nitrogen. In clay soils rich in active minerals, K is subject to fixation, which requires improved application methods to reduce K loss. Instead of traditional broadcasting, increasing fertilizer use efficiency is achieved through improved application with side banding method or fertigation with soluble forms of fertilizers. Literature from the region indicated no response to added K fertilizers on clay soils containing 200 mg K/kg soil. This study aims at reviewing the results of research works conducted in Lebanon with K-fertilization of potato with different rates, application methods and irrigation techniques in two main agro climatic zones of the country.

The review will compare between the use of potassium sulfate as banding in the soil and in the irrigation water by fertigation. In the first winter trial, the splitting into two application dozes gave the higher fresh tuber yield (16 t/ha) despite the absence of significant difference between treatments. Yet, significantly higher elite tubers were found in early K application treatment, indicating the beneficial use from accessible potassium if timed to the plant needs. Also, very late K application towards the physiological maturity stage had a little impact. Despite the low mobility of K in comparison with N, the split application was advantageous also in comparison with a large single application of potassium to initially K deficient soil. Indeed, the ratio of available potassium (exchangeable + dissolved in the solution) to the sum of bivalent Ca and Mg showed a clear dynamic increase with the splitting of potassium.

In the second spring trial, a significant yield increase was observed in the K treatments in comparison with the control, despite the initial K level in the clay soil testing 280 mg/kg soil. Tuber yield increase was associated with significant tuber size improvement (up to 50%) of elite tubers as compared to the control. Monitoring of plant water status revealed an immediate stomato response in the K treated plots to

water deficit during the peak of water demands in the middle of the day. An evidence of improved water use with K application is the field water use efficiency indicating a better water use and higher yield produced by a unit of applied water in the K supplemented treatments.

In the third trial, K uptake by tubers correlated well with tuber DM yield. In the soil application plots, K uptake by tubers was significantly higher in the drip-irrigated treatment in comparison with the sprinkler-irrigated plot. Fertigation with constant concentration throughout the season did not influence or affect this parameter indicating probably the necessity to apply higher concentration of K in the nutritive solution before the maximum plant development stage. The peak of dry matter production in shoots was observed at the maximum development stage (72 DAS) for N0 while it was at the physiological maturity stage for other treatments. The equilibrium in partitioning of dry matter between tubers and shoots occurred first in the drip-irrigated plot with K banding in the soil. This explains the higher value of dry matter production obtained in tubers at the physiological maturity stage. It could be due to early translocation of dry matter from the aboveground parts to the sink. At physiological maturity the dry matter shoot/tuber ratio (0.46) was close to those obtained by fertigation.

The observations from trials run in Lebanon allow retrieving the following remarks:

1. In the traditional potato production with fertilizer application in the soil and furrow irrigation, emphasis should be put on splitting of K application into two doses. The late K application had not been advantageous to the crop. Large single K application applied at sowing was not beneficial to maintain the K potential, i.e., the ability of the soil to keep providing the plants with available potassium, through maintaining its concentration in the soil solution.
2. In case of improved micro irrigation techniques, the soil application of increased rates of K-fertilizers enhanced the plant resilience to adverse climatic conditions during the hottest midday time. This provided better water use efficiency. It also secured yield increase with a large proportion of elite tubers.
3. The soil application of fertilizers and irrigation by sprinklers and drip provided two extreme cases of plant reaction. Drip system and fertigation allowed for higher yields and improved translocation of dry matter and K from shoots to tubers.

The literature indicates that a response to K fertilizers could be expected in soil presenting less than 200 mg/kg of exchangeable potassium. This was the case for a highly demanding crop like potato grown in loamy soil. However, while grown on clay soils with a relatively higher cation exchange capacity, potato responded even to K application when the soil testing showed a value close to 300 mg/kg soil.

1. Introduction

In Lebanon, potato occupies a surface of 14,800 ha (FAO, 2000) corresponding to 17% of the irrigated land. The Bekaa valley is the largest production area in the country, with more than 67% of total potato production located on prime land. The Mediterranean climatic conditions and topography of Lebanon allow for three potato seasons. On the coastal plain it is a major winter crop relying completely on rain and partly on supplemental irrigation. This crop is generally fertilized by soil application and irrigated by furrow with rare implementation of sprinkler systems.

In the Bekaa valley, potato is a main spring and summer crop. The spring season extends from March till August while the summer season is short and starts in June and lasts until October. Due to seasonal rainfall distribution, spring and summer potato depend entirely on irrigation, with an average yield of 20-25 t/ha of fresh tubers (FAO, 2000). Regarding cultural practices, elite and class A seeds are used for the spring seasons only, while lower class seeds generally from the first harvest, are used for the winter season. Yield ranges between 10 and 20 t/ha on the coastal area compared to 30-50 t/ha in the inner Bekaa plain. A consistent difference in the obtained yield of winter season may be partly explained by the seed quality.

In general, potato is cropped within a rotation consisting of wheat-potato-vegetable or legume rotation and irrigated by macro sprinklers. In comparison with vegetable monoculture, such crop alternation was more efficient in controlling soil-groundwater contamination with nitrates in the Central Bekaa plain-Lebanon (Darwish et al., 2002; Moeller et al., 2003). For adequate growth, potato requires large amounts of potassium and nitrogen. A total of 150 kg N/ha and 240 kg K/ha were removed by 50 t of seeds (Rowell, 1994). Phosphorus and minor elements are generally required in smaller amounts (Vander Zaag, 1981).

Conversely to phosphorus, which increased leaf area index during the early stage of growth and hastened the senescence of leaves towards the end of the growing season, potassium increased leaf area index considerably later in the season while delaying the senescence of leaves (Harris, 1992). Potassium reaches its maximal values in the whole canopy by 45 days after emergence. Thereafter, a marked decrease can be observed due to remobilization, translocation or littering of leaves, with maximal translocation to the sink between 60 and 75 days after emergence (Kolbe and Stephan-Bekman, 1997). In clay soils rich in active minerals, K is subject to fixation, which requires improved application methods to reduce K loss (Rowe, 1993). Instead of traditional broadcasting, increasing fertilizer use efficiency is achieved through improved application with side banding method or fertigation with soluble forms of fertilizers (Mohammad et al., 1999; Papadopoulos, 2000).

Potassium is absorbed in large quantities by potato plants, but it tends to reduce dry matter content when applied in excess amount, notably on light texture soils. But this effect is less pronounced on table potato (Vander Zaag, 1981). Potassium applied through the irrigation stream gave higher relative yield in comparison with basal application (Westerman and Kleinkoph, 1985). Insufficient potassium can result in reduced tuber yield and size. Literature from the region indicated no response to added K fertilizers on clay soils containing 200 mg K/kg soil (Ryan et al., 1981). This study aims at reviewing the results of research works conducted in Lebanon with K-fertilization of potato with different rates, application methods and irrigation techniques in two main agro climatic zones of the country. It covers the main production zones: in the coast in winter and in central Bekaa in spring-summer. In its first part, the report will focus on winter potato cropping system grown along the coastal Lebanese strip on K deficient loamy alluvial soil. The second part will focus on spring potato grown in Central Bekaa Valley on clay soils with adequate initial level of available K under dry Mediterranean climate.

2. Materials and Methods

The review will compare between the use of potassium sulfate as banding in the soil and in the irrigation water by fertigation. In trial 1, the soil was deficient in exchangeable K with a level equivalent to 140 mg/kg soil. The experiment covered the fertilization of table potato with one rate of potassium fertilizers (K_2SO_4) split into several dozes (Al Khoury, 2000). So, 400 kg/ha K_2O were split into four application treatments (Table 1). In this experiment, 250 kg N/ha were split into two equal application doses at planting and 45 days after emergence, while 200 kg of superphosphate were applied once at planting time. Supplemental irrigation was practiced by furrow application. Harvest was done 108 days after planting.

The second part of the study will focus on spring potato (Table 1, trial 2) grown on soils with apparently adequate K (280 mg exchangeable K/kg soil). It aimed at studying the effect of different rates of potassium fertilization on the physiological behavior, growth and tuber yield (Karam et al., 2001). Treatments consisted of K banding at sowing in four different rates (Table 1). On the same experimental station (Tel-Amara), another experiment with table potato had been going on within the Regional Cooperation Project RAW/5/002 and aimed at analyzing the impact of fertilization and irrigation methods on crop performance and N recovery using ^{15}N techniques.

It was done through comparing the traditional methods with the application of nutrients in soluble form using fertigation techniques with reliance on drip systems (Darwish et al., 2003). The efficiency of K application in the soil will be compared with the equivalent input of soluble K_2SO_4 under different rates of simultaneous N application.

Table 1. Trials run in Lebanon with potato reflecting different K-fertilization methods and irrigation practices.

Region	Trial	Time of application	Ways of application and irrigation method	Treatments (K_2O, kg/ha)				Source
				K1	K2	K3	K4	
Coastal area	1	At sowing	Soil banding Furrow	400	200	300	200	Al Khoury, 2000
		60 DAS		-	200	100	100	
		90 DAS		-	-	-	100	
Central Bekaa	2	At sowing	Soil banding Drip	K0	120	240	360	Karam et al., 2001
Central Bekaa	3	At sowing	Soil banding Sprinkler (Ncs)	K_2O (kg/ha)	(N kg/ha)			Darwish et al., 2000
			Soil banding Drip (Ncd)	500	N1	N2	N3	
		Continuous with stable concentration	Fertigation drip	500	120	240	360	

3. Results and Discussion

In the first winter trial, the splitting into two application dozes (K2 and K3) gave the higher fresh tuber yield (16 t/ha) despite the absence of significant difference between treatments (Figure 1). Yet, significantly higher elite tubers were found in K3 treatment, indicating the beneficial use from accessible potassium if timed to the plant needs. Also, very late K application towards the physiological maturity stage like in K4 treatment had a little impact. Despite the low mobility of K in comparison with N, the split application was advantageous also in comparison with a large single application of potassium to initially K deficient soil. This characterizes the high soil fixation power (Sayegh et al., 1990; Darwish et al., 2002) and competition from bivalent cations in Ca-saturated soil on the Lebanese coast (Darwish, 2001). Indeed, the ratio of available potassium (exchangeable + dissolved in the solution) to the sum of bivalent Ca and Mg showed a clear dynamic increase with the splitting of potassium, notably in K3 and K4 (Figure 2). However, the available K in K4 was not efficiently used due to late application towards plant maturity stage. There is little evidence of use of residual K by succeeding crops given the soil richness in active minerals (Sayegh et al., 1990). The slight decrease in the ratio in treatment K3 might be explained by higher K uptake that reflected on better tuber size. This supports the concept on the positive effect of the right timing of application as a precondition of good management practice.

In the second spring trial, a significant yield increase was observed in the K treatments in comparison with the control (Karam et al., 2001), despite the initial K level in the clay soil testing 280 mg/kg soil. This level is considered above the threshold of optimum level as based on soil analysis (Ryan et al., 1996). Such output points to potato high demands to K input. Tuber yield increase was associated with significant tuber size improvement (up to 50%) of elite tubers as compared to the control.

Monitoring of plant water status revealed an immediate stomato response in the K treated plots to water deficit during the peak of water demands in the middle of the day. Transpiration and photosynthesis curves declined in the hottest time of the day. The repartitioning of dry matter showed an accumulation in the aboveground parts indicating possible adverse climatic conditions affecting the translocation to the sink. It is well know that K supports plant turgor by maintaining the pressure in the guard cells surrounding stomata. This is followed by an influx of K that reduces the aperture of the stomata, thus contributing to the regulation of water uptake and rate of transpiration. This factor might explain the smaller sizing in the tubers of K deficient treatments accompanied by a higher dry matter content and specific gravity. An evidence of improved water use with K application is the field water use efficiency indicating a better water use and higher yield produced by a unit of applied water in the K supplemented treatments (Figure 3).

In the third trial, K uptake by tubers correlated well with tuber DM yield (Figure 4). In the soil application plots, K uptake by tubers was significantly higher in the drip-irrigated treatment (Ncd) in comparison with the sprinkler-irrigated plot (Ncs). Fertigation with constant concentration throughout the season did not influence or affect this parameter indicating probably the necessity to apply higher concentration of K in the nutritive solution before the maximum plant development stage. K uptake could benefit from this approach, as plants remove 60% of their K need before the end of maximum plant growth (Tisdale et al., 1995).

The peak of dry matter production in shoots was observed at the maximum development stage (72 DAS) for N0 while it was at the physiological maturity stage for other treatments. The equilibrium in partitioning of dry matter between tubers and shoots occurred first in the drip-irrigated plot with K banding in the soil (Ncd). This explains the higher value of dry matter production obtained in tubers at the physiological maturity stage. It could be due to early translocation of dry matter from the aboveground parts to the sink. At physiological maturity the dry matter shoot/tuber ratio was close to those obtained by fertigation (Table 2). However, at the maximum development stage, the shoot/tuber ratio for Ncd was the lowest among all treatments.

Table 2. Soot/tuber dry matter ratio in potato crop at three phenological stages grown in Lebanon with different fertilization and irrigation practices

Treatment	Full flowering 59 DAS	Maximum development 72 DAS	Physiological maturity 103 DAS
N0	3.04	1.03	0.43
N2	3.45	1.45	0.50
Ncd	6.51	0.91	0.46
Ncs	8.81	2.03	0.83

For the sprinkler-irrigated treatment (Ncs), the equilibrium was reached later in the season caused by an important vegetative growth at later stages: 3800 kg/ha of dry matter versus 2900 kg/ha for the fertigated treatment. The plants in Ncs treatment might have benefited from the single large application of nutrients, reflected trough higher K removal in shoots early in the season (Figure 5), coupled with larger watering events in comparison with the drip system. This promoted vigorous plant growth that could have delayed the translocation of dry matter to the sink. Consequently, the peak of dry matter accumulation in tubers of the sprinkler treatment was not obtained towards the physiological maturity stage. At this stage, the shoot/tuber ratio was the highest (0.83) for Ncs (Table 2). The fertigation and drip irrigation treatments, N2 and Ncd showed similar trend of dry matter yield in tubers accompanied by higher rate of K uptake during potato growth stages (Figure 6). This may be attributed to the suitability of K fertigation and even soil application coupled with the drip system in optimizing leaf senescence and enhancing crop maturity.

Potassium acts in carbohydrate formation and transformation and movement of starch from leaves to tubers (Vander Zaag, 1981). The translocation of K in the Ncs treatment was delayed up to the physiological maturity stage (Figure 7). This observation disagrees with an earlier statement on the timing of highest K translocation to tubers in potato between 75-90 DAS (Kolbe and Stephan-Beckmann, 1997). The curves of K uptake by shoots and tubers met at 103 DAS; while the relative distribution of K in shoots and tubers was equivalent to 50% each (Table 3). For Ncd treatment, K removal by tubers at the physiological maturity stage was significantly higher among all treatments. The crossing of K removal by shoots and tubers occurred at the maximum development stage (Figure 8), i.e., much earlier than all other treatments. At this stage, K relative distribution in shoots and tubers was equivalent to 46.8% and 53.5% respectively. At physiological maturity, the distribution was 35% versus 65% in respective plant parts. In fertigated treatments, K application was evenly split across the season. Therefore, K transfer from shoots to tubers took place later than in Ncd, around the physiological maturity stage. Also, a highest shoot/tuber potassium ratio was observed in the sprinkler treatment (Table 3). But, this ratio was almost equal among fertigated treatments at maximum development and physiological maturity stages (Figure 9) regardless of the rate of N application.

Table 3. Soot/tuber potassium ratio in potato crop at three phenological stages grown in Lebanon with different fertilization and irrigation practices

Treatment	Full flowering 59 DAS	Maximum development 72 DAS	Physiological maturity 103 DAS
N0	5.28	1.54	0.50
N2	5.51	2.08	0.73
Ncd	8.94	0.88	0.53
Ncs	13.45	2.54	1.00

4. Conclusion

The observations from trials run in Lebanon allow retrieving the following remarks:

4. In the traditional potato production with fertilizer application in the soil and furrow irrigation, emphasis should be put on splitting of K application into two doses. The late K application had not been advantageous to the crop. Large single K application applied at sowing was not beneficial to maintain the K potential, i.e., the ability of the soil to keep providing the plants with available potassium, through maintaining its concentration in the soil solution.
5. In case of improved micro irrigation techniques, the soil application of increased rates of K-fertilizers enhanced the plant resilience to adverse climatic conditions during the hottest midday time. This provided better water use efficiency. It also secured yield increase with a large proportion of elite tubers.
6. The soil application of fertilizers and irrigation by sprinklers and drip provided two extreme cases of plant reaction. Drip system allowed for higher yields and improved translocation of dry matter and K from shoots to tubers. Fertigation also proved better in comparison with the sprinklers, which were associated with a delay in the plant senescence, dry matter and K transfer to the sink. Excessive amounts of N applied through fertigation did not improve DM production but the continuous even K application with irrigation water improved element translocation from shoots to tubers, comparable with the lowest N rates. To hasten K transfer from shoots to tuber it is worth trying higher concentration of K before the stage of maximum plant growth.
7. The literature indicates that a response to K fertilizers could be expected in soil presenting less than 200 mg/kg of exchangeable potassium. This was the case for a highly demanding crop like potato grown in loamy soil. However, while grown on clay soils with a relatively higher cation exchange capacity, potato responded even to K application when the soil testing showed a value close to 300 mg/kg soil.

Acknowledgment

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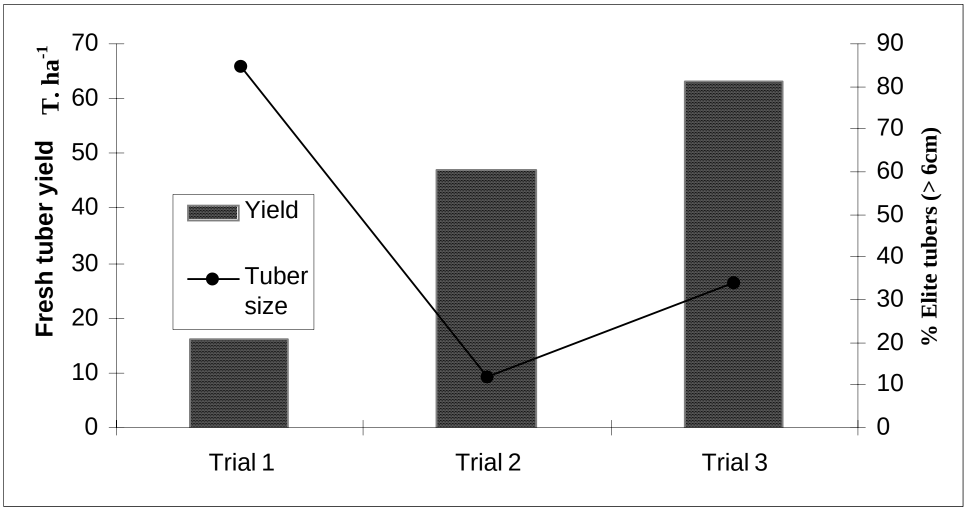

Figure 1. Fresh potato tuber production and calibration with different K and N rates in Lebanon. (Sources: Al Khoury, 2000; Karam *et al.*, 2001; Darwish *et al.*, 2003).

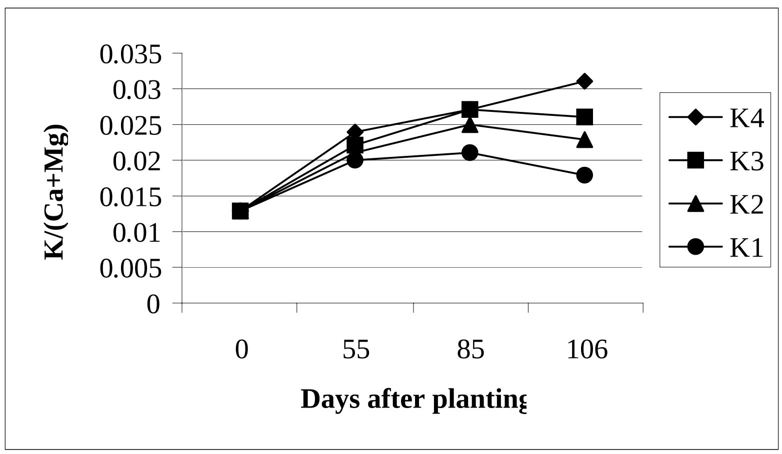

Figure 2. Dynamic change in the K/(Ca+Mg) ratio in the soil of plots treated with potassium at different growth stages (Source: Al Khoury, 2000).

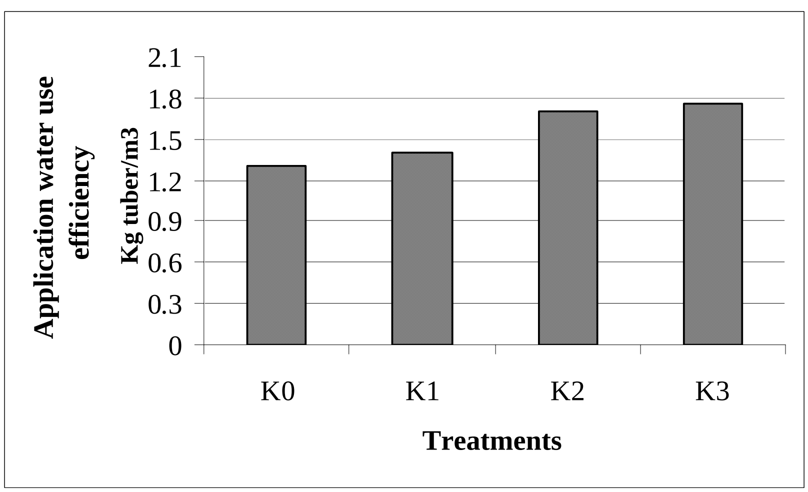

Figure 3. K contribution to water use efficiency by potato (kg tuber/m^3 of applied water) in Lebanon (Source: Karam et al., 2001).

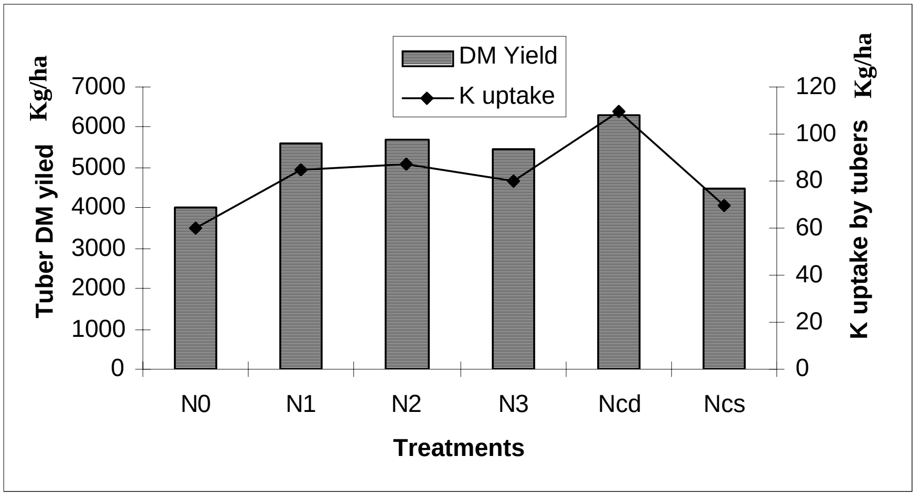

Figure 4. Dynamic of tuber DM yield in table potato and K uptake by tubers in a spring season grown in Lebanon (Source : Darwish *et al.*, 2002).

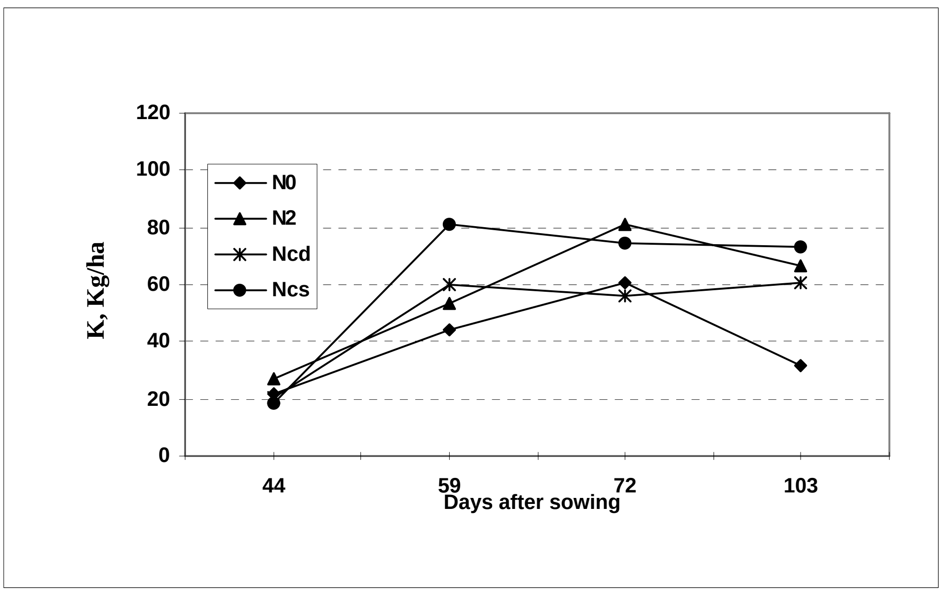

Figure 5. K removal by spring potato shoots at different growth stages (Source : Darwish *et al.*, 2002).

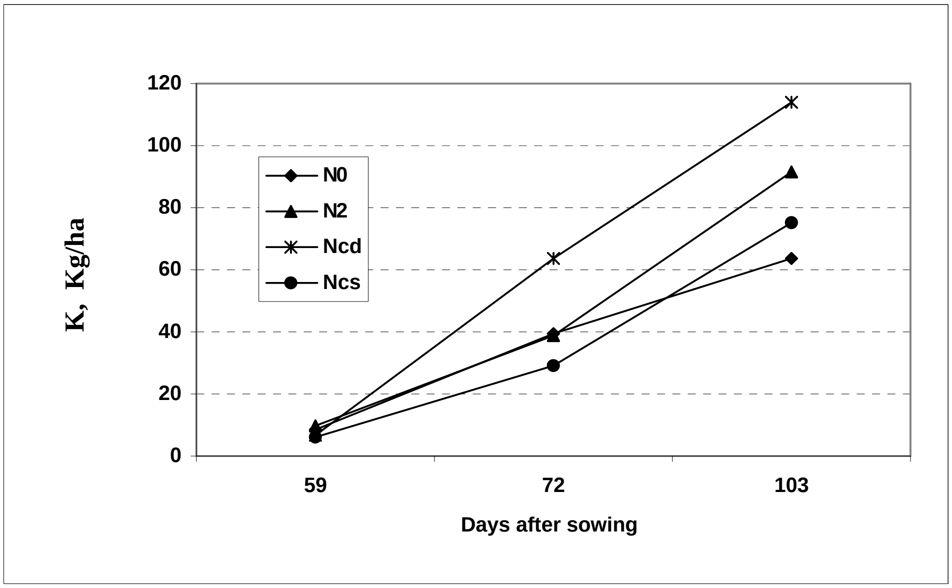

Figure 6. K uptake by spring potato tubers **(Source : Darwish *et al.*, 2002).**

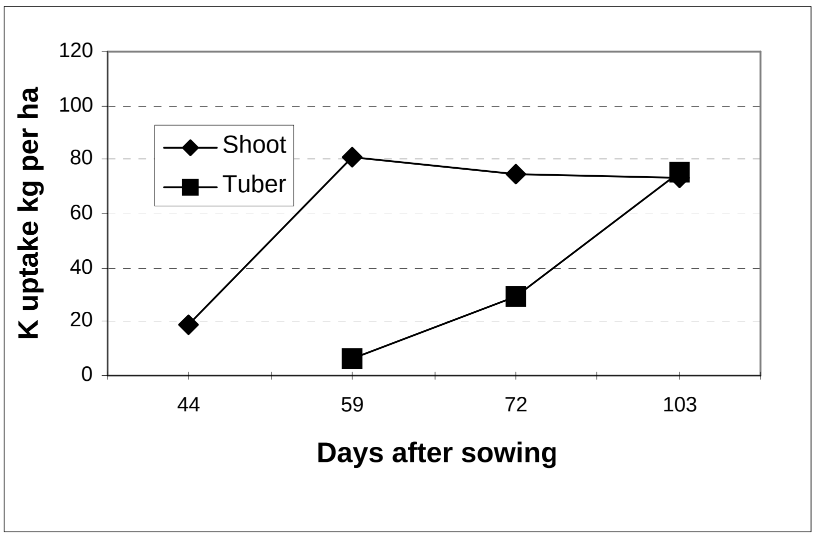

Figure 7. Dynamic of K uptake by potato crop fertilized in the soil and irrigated by macro sprinklers **(Source : Darwish *et al.*, 2002).**

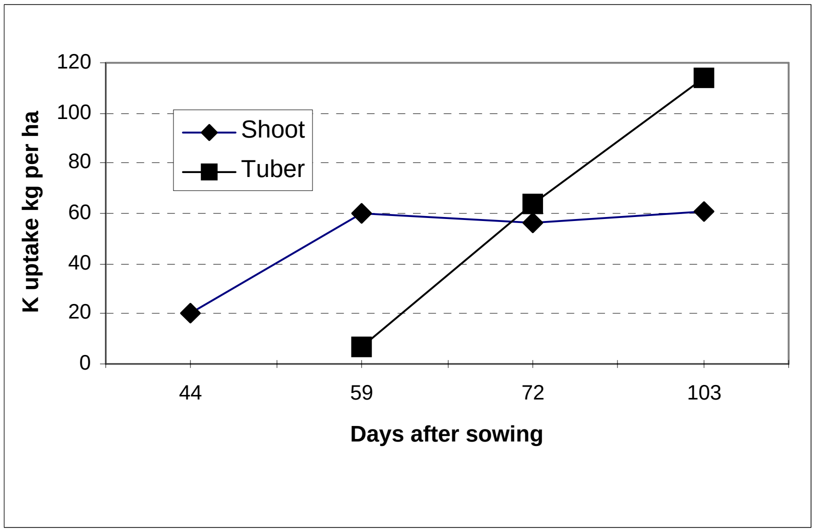

Figure 8. K uptake by spring potato after basal fertilizer application and irrigation with drip system (Source : Darwish *et al.*, 2002).

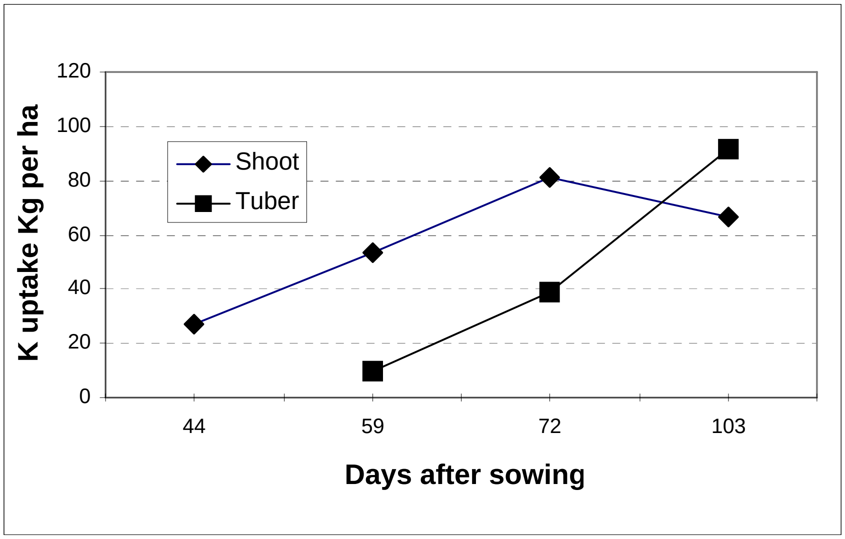

Figure 9. K uptake by spring potato fertilized and irrigated by fertigation with drip system (Source : Darwish *et al.*, 2002).