

Research Findings



Photo 1. A view of the potato field trial during spring 2015. Photo by authors.

Potato Performance under Different Potassium Levels and Deficit Irrigation in Dry Sub-Humid Mediterranean Conditions

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Abstract

A trial on potato (*Solanum tuberosum* L.) response to three doses of potassium (K) under deficit irrigation was conducted under dry sub-humid conditions in Bekaa plain, Lebanon, between 8 April 2015 and 31 July 2015. Grown on clay, neutral pH, Eutric Fluvisol, table potato crop (cv. Spunta) was fertilized at three levels of K: 120 (K₁), 240 (K₂) and 360 kg K₂O ha⁻¹ (K₃), tested against a zero-K treatment (K₀). All treatments received equal amounts of nitrogen (150 kg N ha⁻¹) and phosphorus (150 kg

P₂O₅ ha⁻¹). The crop, subjected to mild deficit irrigation (85% of evapotranspiration) starting from the shoot development stage, was irrigated with a drip system. Soil moisture was monitored

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throughout the season by moisture sensors inserted at 25 cm and 50 cm soil depth to schedule the irrigation. The crop performance was assessed by measuring canopy temperature and chlorophyll content as a function of the different K applications. The K_3 treatment exhibited higher chlorophyll contents during flowering, tuber initiation and bulking stages. At midday, the K_3 canopy temperature was the lowest (29.6 °C), compared to K_0 (31.0 °C), indicating facilitated stomatal aperture, and consequent carbon exchange rate. These results demonstrate the important role of K in establishing and maintaining carbon translocation from source leaves to sink organs, thus enhancing potato productivity. The final tuber yield increased significantly from 2.3 in K_0 to 3.3 kg m⁻², in K_3 . The average tuber weight and commercial tuber weight were significantly greater in the K_3 treatment while the tuber dry matter content was unaffected by the application of potassium. Further increase in potato tuber yields should be sought through the distribution of K applications during the season, particularly during the crucial stage of tuber bulking, when K requirements rise. Potassium role in regulating plant water relations in potato should be further examined in order to cope with extreme weather conditions that often occur in semiarid and dry sub-humid regions.

Introduction

Water use in agriculture represents around 70% of water consumption in Lebanon (Darwish *et al.*, 1999). In the near future, the competition between domestic and agricultural water use will become more significant. Therefore, it will be necessary to produce as much, and even more, with greater water use efficiency (WUE). Potato is a major cash crop in the Bekaa plain with an area exceeding 19,000 ha (MoA, 2012). Potato is grown in the Bekaa plain in two seasons: spring and summer. However, the average potato yield in Lebanon (23 Mg ha⁻¹) is far below the crop's potential productivity. Such a low yield is attributed to the imbalanced applications of nutrients for intensive potato crop production (Karam *et al.*, 2011). Grown during spring or summer, the crop is highly dependent on irrigation. Potato is considered sensitive to water stress, as an optimum yield could not be attained with 30 to 50% soil moisture depletion (Panigrahi *et al.*, 2001; Onder *et al.*, 2005). The absence of irrigation for two weeks during the tuber ripening stage caused 40% yield loss (Karam *et al.*, 2014). Irrigation management could be combined with optimized fertilizer applications to increase potato yields. An application of potassium (K) fertilizers (120 kg K ha⁻¹) under controlled deficit irrigation (80% of soil field capacity) improved the quantity and quality of potato yield, together with elevated WUE (Abd El-Latif *et al.*, 2011). In Lebanon, both WUE and nitrogen use efficiency (NUE) in table potato were improved by the adjustment of the inputs to estimated crop nutrient demands and available pools (Darwish *et al.*, 2003). Employing an appropriate irrigation schedule and a balanced fertilization by fertigation improved both WUE and NUE (Darwish *et al.*, 2006).

Potato has a high K demand (Haeder *et al.*, 1973; Jansson, 1980; Panique *et al.*, 1997). In addition to facilitating starch accumulation in tubers, K⁺ regulates the amount of water in the plant and plays a role in maintaining turgidity of plant cells. In the absence of sufficient K, crops do not use water efficiently and become less able to withstand water stress during drought periods. Addition of K fertilizer improved water relations of different crops under water stress conditions (Islam *et al.*, 2004). Potassium is also a major player in various metabolic processes such as protein biosynthesis (Belvins, 1985) and osmotic adjustment (Fischer, 1968). Thus, K application enhances N and phosphorous (P) uptake irrespective of soil moisture levels (Baque *et al.*, 2006). Maintaining higher cytoplasmic K levels increased plant drought tolerance (Chow *et al.*, 1990; Cakmak and Engels, 1999). Potassium is also required as a regulator for photosynthetic CO₂ fixation, especially in environmentally stressed conditions. Even in heavy textured soils, known for their high water retention capacity, adequate amounts of K and N fertilization under moderate deficit irrigation (80% of crop evapotranspiration (ETc)) showed positive effects on potato crop performance, productivity and N recovery (Darwish *et al.*, 2006). In poor sandy soils in Poland, with high risks of nitrate leaching, K addition to a rain-fed potato crop positively affected NUE (Grzebisz *et al.*, 2015).

The objectives of the present study were to promote sustainable land management in the largest Lebanese agricultural area in the Bekaa plain through the improvement of potato performance and yields under drought conditions. Different K application rates were tested under a mild deficit irrigation (85% of crop water demand). Fertilizers were applied directly to the soil, while water was applied via drip irrigation. The performance of table potato crop was followed during the spring and summer of 2015, in addition to assessing indicators like canopy temperature and chlorophyll contents.

Materials and methods

A trial on potato response to fertilization and irrigation was conducted in the central Bekaa plain, Lebanon, at the Research Center for Environment and Development, Beirut Arab University (33°47'58.6" N; 35°51'40.8" E), from 8 April 2015 to 31 July 2015 (Photo 1). Soil analysis prior to the experimental work indicated moderate fertilization levels in recent years. The levels of plant available phosphorus (Olsen P) and exchangeable K (ammonium acetate extraction) were indicative of the moderate fertilization of the site (Table 1).

Potato seeds (Spunta variety, Class A seeds) were mechanically sown on 8 April 2015, at a density of 57,000 plants ha⁻¹. The total planted area was 700 m² divided into four blocks, each one divided into four plots in a complete randomized block design.

Table 1. Initial soil properties analyzed in April 2015 at two soil depths.

Soil depth	Textural class	pH	Organic matter	CaCO ₃	Olsen P	Exchangeable K
<i>cm</i>			-----g kg ⁻¹ soil-----		-----mg kg ⁻¹ soil-----	
0-20	clay	7.1	21	190	9.1	250
20-40	clay	7.3	20	170	5.5	150
Levels recommended by the Lebanese Agricultural Research Institute (LARI)					40	300

Treatments consisted of different K rates, as follows: K₀ - zero-K control; and K₁, K₂, and K₃, applied with 120, 240, and 360 kg K₂O ha⁻¹, respectively. Potassium, in the form of potassium sulfate (K₂SO₄) was applied directly to the rows before planting. All treatments received similar N (150 kg N ha⁻¹) and P (150 kg P₂O₅ ha⁻¹) rates (the soil was poor in P), in a split application before sowing and at the time of shoot development (Fig. 1). The crop performance was evaluated at different stages: mid-flowering, full flowering and physiological maturity by sampling four individual plants per plot (Fig. 1). At full maturity (July 30th), six plants were sampled from each plot by digging out the tubers, which were graded (below or above 3.5 cm in diameter), weighed immediately, then a subsample was dried for the dry matter content. ANOVA analysis was performed to check the effect of different levels of K application.

A drip irrigation system was employed (Photo 2). The amount of irrigation water was based on crop demand as determined by the grass evapotranspiration (ET_g) obtained from an agroclimatic station located in central Bekaa as well (33°51'30.5" N; 35°59'12.7" E). The crop coefficient (K_c), varied between 0.4 and 0.9 (FAO, 1969; Papadopoulos, 1988;

1996). Mild deficit irrigation (85% of ET_c) was started at the vegetative development stage and lasted till foliar senescence (Fig. 1). Irrigation scheduling was based on soil water potential measurements read every morning at a depth of 25 cm. Irrigation was launched whenever the soil water potential was close to an average value of 300 mbar. Soil water potential recorded 24 hours after irrigation showed an average value of 100 mbar. Canopy temperature was measured using an infrared thermometer (Raytek: Ray R 3i LT DL2), while chlorophyll content was determined in-situ using a portable chlorophyll meter (Konika Minolta: SPAD 502DL Plus).

Results and discussion

At mid-flowering and tuber initiation (8-Jun), the average vegetative dry weight was 0.175 kg m⁻², and did not differ significantly between treatments despite decreased aboveground matter in K₂ and K₃ treatment plants (Fig. 2). Two weeks later (22-Jun), growth of the aboveground biomass was almost halted. On the other hand, the developing tubers gained about 0.25 kg m⁻²,

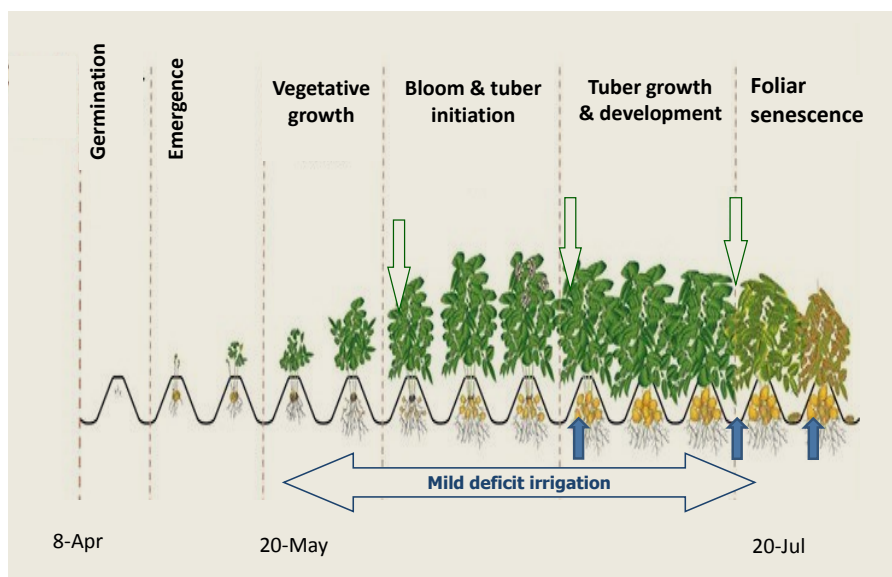


Fig. 1. Representation of the potato sampling in relation to the main stages of the crop. Transparent vertical arrows refer to the sampling dates of shoots (8-Jun, 22-Jun, and 9-Jul), bold arrows to those of tubers (22-Jun, 9-Jul, and 30-July), and the blue horizontal arrow indicates the duration of the mild deficit irrigation.



Photo 2. Drip irrigation systems are still not commonly used by farmers (less than 10%) in Lebanon, despite their advantages and contribution to water saving. Photo by authors.

during the same period (Fig. 2). Tuber biomass was slightly, but significantly, larger among K-fertilized plants.

The application of 360 kg K₂O ha⁻¹ (K₃) gave rise to significantly higher fresh tuber yield, 42% greater than the yield of the K₀ treatment (Table 2). The intermediate K doses applied to K₁ and K₂ were insufficient to increase tuber yields significantly above K₀. These results may indicate that the exchangeable K present in the soil pool (Table 1) is too small to obtain considerable tuber yields. Moreover, with a demanding crop such as potato, increasing K application dose further may result in even larger tuber yields.

While the number of tubers varied from 26-34 tubers m⁻², with no significant influence of K application rates, the latter had an obvious effect on tuber size, though at the highest K dose only (Table 2). Tuber size increased by 67%, from 75 to 126 g, which also had considerable positive consequences on the commercial value of the produce.

In spring potato, the number of shoots emerging from the tuber-seeds and the aboveground biomass developing until tuber initiation, together set the primary potential of the number of initiating tubers. This is the reason why, in potato, sufficient N nutrition is essential at the beginning of the cropping season (Papadopoulos, 1988; Mustonen *et al.*, 2010). The prevalence of inductive environmental factors, such as low temperature and short day-length, determines to what extent this primary tuber potential is realized (Moorby and Milthorpe, 1975; Ewing and Struik, 1992). Potassium does not seem to have any influence on tuber initiation, however, it has a central role in strengthening sink organs and in the regulation of carbohydrate translocation (Haeder *et al.*, 1973). Tuber dry matter content increased slightly with rising K dose, but this was statistically insignificant indicating that the genotypic limits of the cultivar (18-20%) overrule nutritional factors.

A dose of 360 kg K₂O ha⁻¹ is quite similar to that recommended commercially, however, higher tuber yields are expected (Jansson, 1980). The reason for the discrepancy may lie in the timing of K application during the cropping season. Nutrients should be applied when required and as accurately as possible to the uptake zone. The highest K requirement is during the tuber bulking stage, the onset of which is indicated by flowering. The daily N, P, and K requirements of potato tubers during this critical stage are 4.5, 0.3, and 6.0 kg ha⁻¹, respectively. Under optimum conditions, daily yield increase during tuber bulking may exceed 1.0 Mg ha⁻¹ day⁻¹ (Ewing and Struik, 1992). Therefore, an

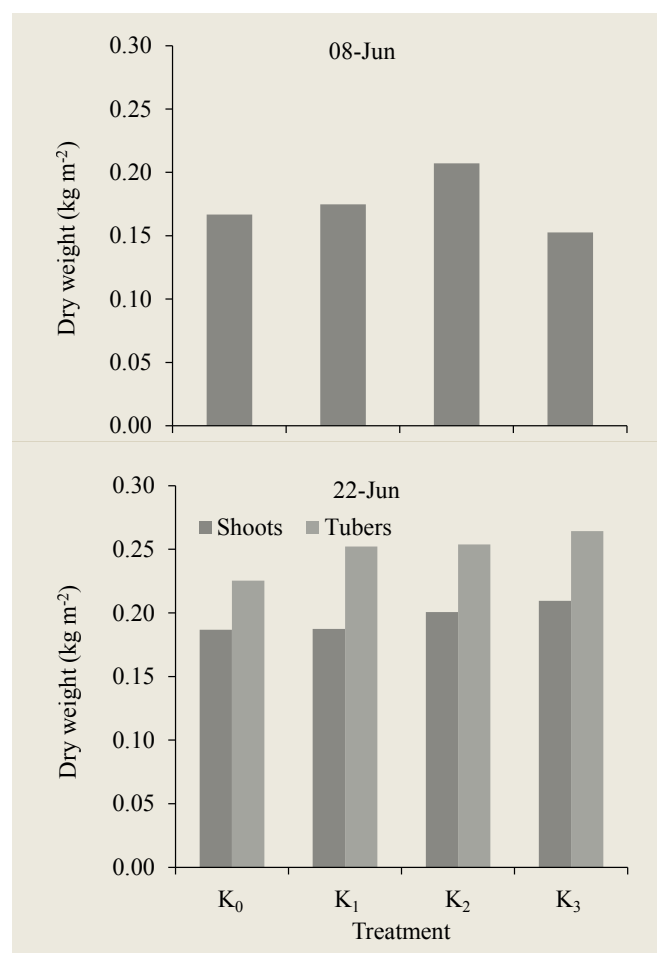


Fig. 2. Effect of K application rates (K₁: 120, K₂: 240 and K₃: 360 kg of K₂O ha⁻¹) on aboveground and tuber growth (kg DW m⁻²) at tuber initiation (8-Jun), and two weeks later (22-Jun).

Table 2. Fresh tuber yield, number of tubers, average tuber size, average size of commercial tubers ($\phi > 3.5$ cm), and tuber dry matter content at full maturity on 30-Jul.

Treatment	Tuber yield	Number of tubers	Average tuber weight	Average commercial tuber weight	Tuber dry matter content
	kg m ⁻¹	Tubers m ⁻²	g		%
K ₀	2.331 ^a	30.9	75.4 ^a	119.0 ^{ab}	19.28
K ₁	2.741 ^{ab}	34.2	80.1 ^a	110.4 ^a	19.39
K ₂	2.664 ^{ab}	33.0	80.7 ^a	122.0 ^{ab}	19.49
K ₃	3.305 ^b	26.2	126.3 ^b	162.5 ^b	19.57

Note: Different letters indicate significant differences ($p < 0.05$) within a column.

adequate supply of the required nutrients at the right N-P-K ratio during the tuber bulking stage would be crucial for further increasing potato yields.

Canopy temperatures were measured on 15-Jun (mid-bloom), 24-Jun (full bloom and tuber initiation) and 9-Jul (tuber growth).

The daily pattern of the canopy temperature had a peak at 13:00 hour (Fig. 3A). The four K treatments followed similar trends.

Midday canopy temperatures were higher on 9-Jul than on 15-Jun. Whereas, on 15-Jun, at tuber initiation, midday temperature was similar among all K treatments. Significant differences occurred later on during the period of intensive tuber growth (Fig. 3B); the higher the K application dose, the cooler the canopy. Plants' leaves are cooled through evapotranspiration; large amounts of water evaporate through stomata carrying the excess heat energy into the atmosphere. Potassium is involved in mechanisms governing stomata aperture (Fischer, 1968) aiming to maintain an appropriate balance between water loss

and carbon assimilation. The role of K in the present study could be indirect; as it supports carbohydrate uploading in leaves and its translocation and unloading in tubers, thus enhancing the overall carbon demand in the plant (Lalonde *et al.*, 2004). The maintenance of high carbon demand puts significant pressure on the carbon assimilation processes, thus promoting prolonged stomatal aperture that in turn leads to extensive transpiration and lowered foliar temperature.

High K application dose was associated with increased chlorophyll content in leaves already at full bloom and tuber initiation (Fig. 4). This difference between K treatments also lasted until tuber maturation (data not shown). The retention of high chlorophyll content in leaves quite close to foliar senescence is another indicator of the sustained carbon sink demand by the growing tubers under sufficient K availability. Thus, high K dose preserves intensive physiological activity, delays plant senescence, and contributes to significant yield increases.

Monitoring soil moisture content using sensors at 25 and 50 cm depths allowed thorough adjustment of the fertilizer doses and timing of irrigation. Drip irrigation conveys the water to the exact site of consumption. Continuous deficit (0.85 ETc) drip irrigation allowed the maintenance of relatively steady and spatially homogeneous moisture content throughout the season, varying from 0.34-0.45 m³ water m⁻³ soil, before and after irrigation. These technologies can enable significant water savings and increased WUE. Indeed, an overall amount of 270 mm was applied to the experimental plot, compared with 345 mm water applied by farmers during the same season, using sprinklers. In the present study, WUE varied from 0.009-0.012 kg tubers kg⁻¹

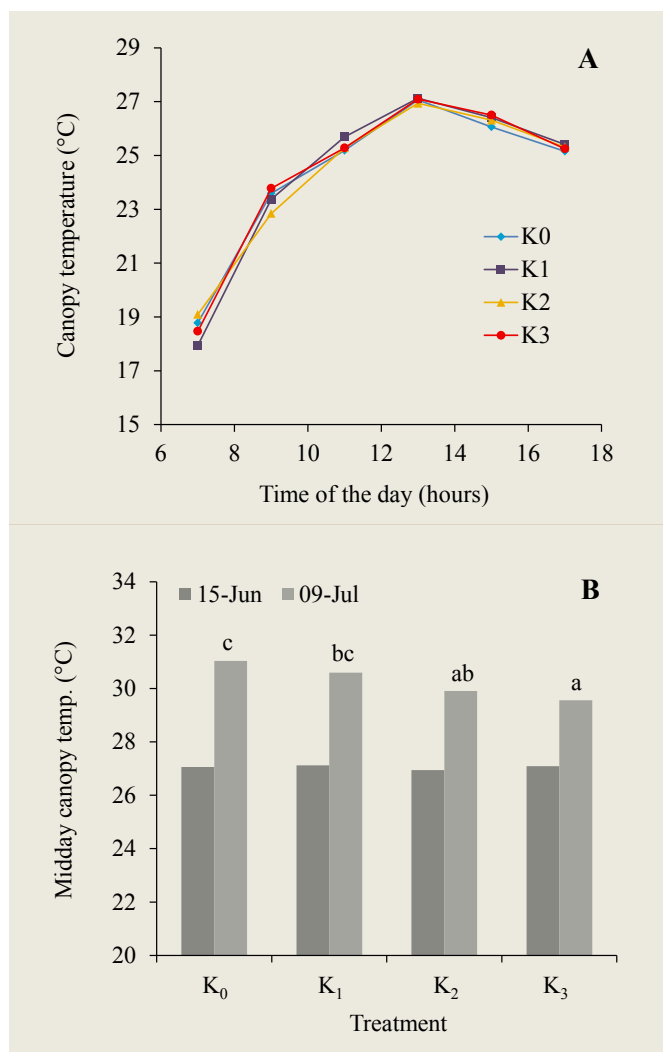


Fig. 3. The effect of the potassium level (K₁: 120, K₂: 240 and K₃: 360 kg of K₂O ha⁻¹) on the daily pattern of potato canopy temperature on 15-Jun (A) and on the midday canopy temperature on 15-Jun and 9-Jul (B). Different letters indicate significant differences (p<0.05) on 9-Jul.

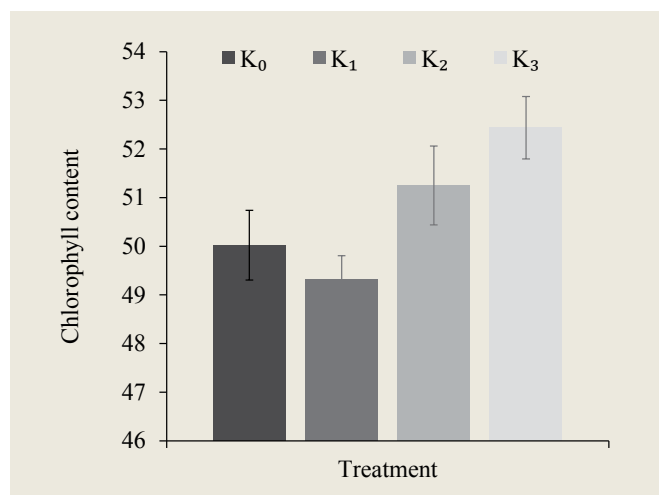


Fig. 4. Chlorophyll content (relative arbitrary units) in potato leaves under different K application doses, measured on 24-Jun, at full bloom and tuber initiation. Bars indicate mean of 32 measurements (4 plants, 8 leaves per plant) ±SE.

water applied, in K_0 and K_3 treatments, respectively. Nevertheless, the actual role of K regarding water saving and WUE in the present study remains unclear. On the heavy textured soil, and with the irrigation regime and technique employed, the mild deficit irrigation was probably not enough to cause significant water stress. Thus, the improved WUE was achieved due to K-promoted increase in productivity rather than by reduced water requirements.

The direct role of K in potato plants coping with water stress is of special importance in the dry sub-humid and semi-arid Mediterranean region. Heat waves, known also as Khamseen, coming from the neighboring Sahara desert or Arabian Gulf often occur during April to June. The sharp increase in temperature, accompanied by a drastic decline in air humidity, challenges the fragile water status of potato plants, particularly during tuber initiation and growth (Bustan *et al.*, 2004). Elucidating K significance in this respect would require direct measurements of plant water potential, stomatal conductance, and transpiration.

Conclusions

Potassium application dose of 360 kg K_2O ha⁻¹ promoted a significant increase, 67%, in potato tuber yield, compared to K doses of 0, 120, and 240 kg K_2O ha⁻¹. While showing no influence on the vegetative growth, K had remarkable effects on tuber size, hence on yield. The highest K dose gave rise to higher chlorophyll content and to delayed foliar senescence. Midday leaf temperature was reduced at the higher K dose, indicating extensive and prolonged stomatal conductance. These results demonstrate the important role of K in establishing and maintaining carbon translocation from source leaves to sink organs, thus enhancing potato productivity. Further increase in potato tuber yields should be sought through the increase of the highest K dose to 480 kg K_2O ha⁻¹ and/or distribution of K application along the season, particularly during the crucial stage of tuber bulking, when K requirements rise. Potassium's role in regulating plant water relations in potato should be further examined in order to cope with extreme weather conditions that often occur in semi-arid and dry sub-humid regions.

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