Technical Session III :

K Nutrition Management of Annual Crops

Potassium Effects on Plant Growth, Development, Yield and Quality of Wheat

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Introduction

The main factors limiting wheat yield in the Negev are water and nitrogen. Since wheat requires a relatively small amount of potassium, farmers usually do not analyze soil for its presence, and do not add potassium fertilizers. However, potassium is one of sixteen essential nutrients required for plant growth and reproduction.

While potassium is not a constituent of any plant structures or compounds, it is essential in nearly all processes needed to sustain plant growth and reproduction (Beaton and Sekhon, 1985). Plants deficient in potassium are less resistant to drought and high temperatures. However, potassium deficiency often does not produce clear symptoms on wheat leaves, and therefore is difficult to identify.

Lack of fertilization over long periods could increase potassium deficiency, and further raise the question of potassium application requirements. Over the last four years, several experiments examined the availability of potassium and it's effect on yield, and uptake and quality of wheat. This paper presents results from these experiments.

Potassium Content in Soils

Precise fertilization is necessary to ensure grain yield, increase profitability, and reduce environmental pollution. In the Negev region, pre-sowing soil tests are usually conducted to determine optimal quantities of fertilizer for wheat. An accurate bioassay was developed to determine soil nitrogen availability (Amir and Ephrat, 1971; Amir *et al.*, 1994), and this bioassay has been used for almost twenty years. Different extractants remove quite different amounts of nutrients from soils. The most common extractions used for potassium in this region are calcium chloride that extracts the water-soluble potassium and approximately twenty percent of the exchangeable potassium, and ammonium acetate that extracts the exchangeable potassium.

The main problem with these methods is that they require many small soil samples to be taken from the field and the extraction methods require strict extraction conditions while yet the correlation to potassium uptake is very low. Higher correlation was found between potassium uptake and the potassium-bioassay than with either ammonium acetate or calcium chloride extractions (Bonfil *et al.*, 2001). Wheat sampling from commercial fields from the last season showed that neither ammonium acetate nor calcium chloride extractions correlate with potassium uptake (**Fig. 1**), but there is a higher correlation between the potassium bioassay result and the potassium uptake.

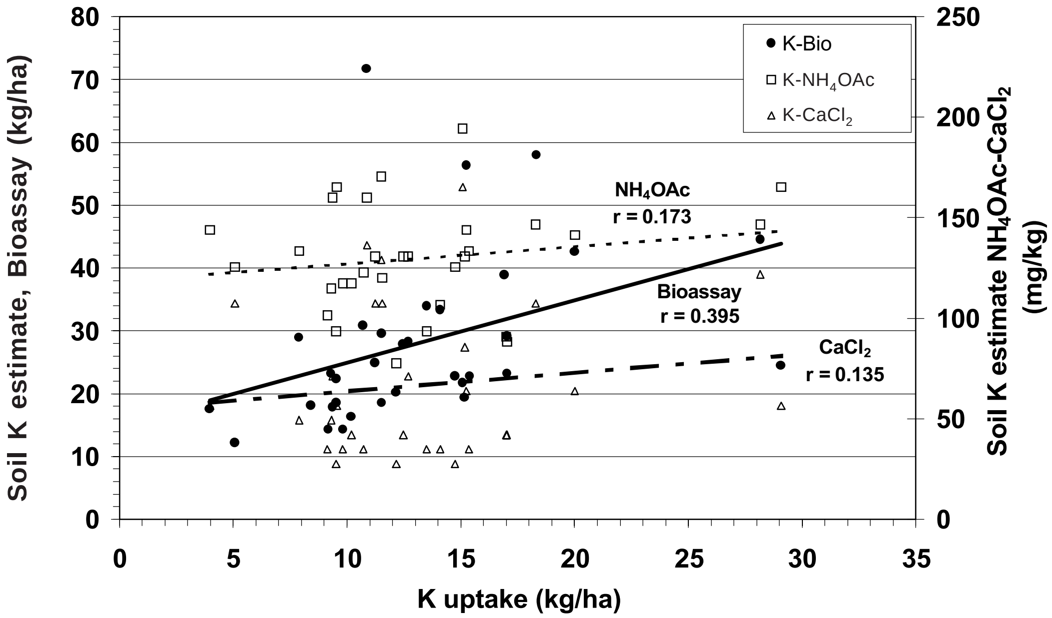

Figure 1. Correlation between potassium uptake by wheat grown in commercial fields (2001) and three extraction methods.

Available potassium varies greatly between soils (**Table 1**). Differences also exist in potassium composition, some soils contain higher levels of water-soluble potassium, and while in others the majority comes from exchangeable potassium (**Fig. 2**).

Table 1. Available potassium content in soils and uptake by wheat plants

Extraction method	*Farm plots*[a]		*Gilat Dryland Experimental plot*		*Gilat Irrigation Experimental plot*	
	mean	*range*	*mean*	*range*	*mean*	*range*
$CaCl_2$ (µg g^{-1})	54	18-165	82	24-153	58	24-168
NH_4OAc (µg g^{-1})	124	70-194	156	74-206	124	72-199
Bioassay (kg ha^{-1})	307	91-846	207	87-417	269	110-584
Uptake (kg ha^{-1})	113	10-296	68	4-150	46	20-101

a) Plots= Farms, represent commercial wheat fields all over the Negev; Gilat Dryland, represent non irrigated experimental plots in Gilat permanent wheat experiment, Gilat Irrigation, represent experimental plots in Gilat that received supplemental irrigation.

Since wheat requires relatively small amounts of potassium, the in vivo potassium uptake by wheat is always lower than the quantity that the soil can supply (**Table 1**), thus emphasizing the situation that even when potassium was not applied to these soils for a long period, and the water-soluble potassium levels declined, the soils maintained a high buffer capacity of potassium and supplied enough potassium to wheat. It should be noted that this is not the situation everywhere (Randall *et al.*, 1997), it is dependant on soil type and buffer capacity of potassium. Thus, all data shown here are results from fields where potassium is not a limiting factor for growing wheat.

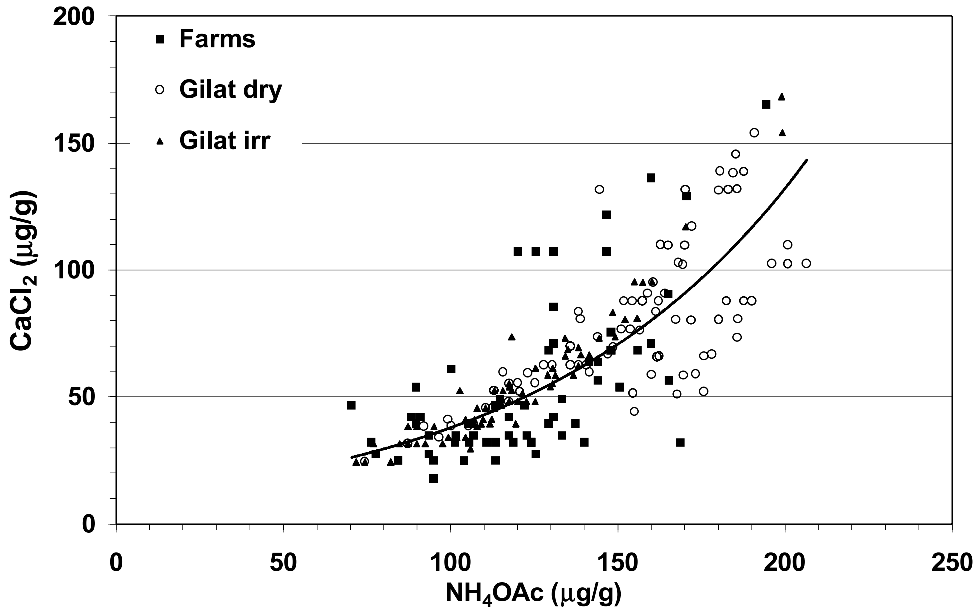

Figure 2. Available potassium content in soils (Negev, Israel).

Potassium uptake by wheat plants

Potassium percentages in dry matter range from 0.2 to 6%, and can limit yield production when K content is less than 1%, however the percentage of potassium in fresh matter is more accurate (Beaton and Sekhon, 1985; Leigh and Johnston, 1983; Leigh and Wyn Jones, 1984). In Gilat, wheat development stage and year were found as the main effects on percentage of potassium in wheat dry matter (**Table 2**). In all samples potassium content was at least 1%, and before heading (30 or 60 days after emergence) the content was more than 2%. Potassium content in wheat plants at heading (90 or 120 days after emergence) increased from about 1% in the 1998 season (after first KCl application of 250 kg K per ha) to 1.5-2% after another fertilization (total application of 500 kg K per ha).

Table 2. Effect of potassium (KCl) fertilization on potassium content in wheat plants at various stages

Year	*Plot*[a]	*DAE*[b]	*K%*		*K mmol kg^{-1}*		*K kg ha^{-1}*	
			–K	*+K*	*–K*	*+K*	*–K*	*+K*
1998	DRY	90	1.21a	1.14a	nd[c]	nd	55.8a	54.4a
	IRR	120	1.06a	1.07a	nd	nd	53.4a	62.1a
1999	DRY	30	2.61a	2.86a	nd	nd	4.5a	5.8a
	IRR	30	2.96a	3.06a	nd	nd	12.8a	10.2a
	IRR	60	2.17b[d]	2.64a	141b	205a	22.6b	30.6a
	IRR	90	1.60a	1.62a	155b	166a	37.7a	36.8a
2000	DRY	30	3.46a	3.40a	nd	nd	7.3a	7.0a
	DRY	60	2.32a	2.21a	207a	207a	50.1a	52.0a
	DRY	90	1.52a	1.48a	338a	352a	49.1a	43.5a
	IRR	30	2.30a	2.37a	177a	183a	2.8a	2.4a
	IRR	60	2.66a	2.86a	169a	177a	24.3a	28.2a
	IRR	90	2.00a	2.14a	183a	188a	46.1a	50.9a

DRY, IRR= represents non-irrigated and irrigated experimental plots in Gilat permanent wheat experiment respectively. DAE = day after emergence.nd = not detected.Within years, plot and DAE, means followed by the same letter are not significantly different using LSD mean separation procedure.

The cytoplasm potassium content in requirements for protein synthesis and the cytoplasmic function probably needs to maintain the cytoplasmic concentration of K in the range of 100 to 200 mM (Leigh and Wyn Jones, 1984). In our experiments, potassium application had no effect on the cytoplasm potassium content (**Table 2**), except in the irrigated field (1999-IRR) that exhibited a small increase. Drought caused the highest levels found in the plants from the rainfed plot (2000-DRY-90). Potassium application had no effect on potassium uptake (**Table 2**), and the difference in K uptake must have been related to differences in total dry matter accumulation.

In our experiments, potassium application usually had no effect on the potassium content at harvest (**Table 3**). Although application of 500 kg K per ha, K yield was only around 50 kg K per ha, which was similar to K yield in the unfertilized plots. This amount is typical for water limiting conditions (Beaton and Sekhon, 1985). Like K uptake, potassium also had no effect on wheat yield (**Table 4**). There are some other indications that show that potassium fertilization can increase grain yield (Beaton and Sekhon, 1985). In our experiments, potassium did not affect yield production, at the same time, year, water, nitrogen, and phosphorus supply were the main factors (not shown).

Table 3. Effect of potassium fertilization on K content in wheat at harvest

Year	*Plot*	*Grain K (g kg^{-1})*		*Straw K (g kg^{-1})*		*K Yield (kg ha^{-1})*	
		–K	*+K*	*–K*	*+K*	*–K*	*+K*
1998	DRY	4.3#[a]	4.5#	13.2a	12.9a	55.8a	56.5a
	IRR	3.4b	3.8a	11.0b	13.7a	46.5b	55.0a
1999	IRR	3.4a	3.3a	12.3a	12.6a	40.2a	37.3a
2000	DRY	4.3a	4.4a	18.8a	19.1a	68.7a	62.9a
	IRR	3.1a	2.9a	16.6a	15.5a	64.3a	56.1b

a) # = Significant N X P X K interaction; within years and plot, means followed by the same letter are not significantly different using LSD mean separation procedure.

Table 4 Effect of potassium fertilization on wheat yield

Year	Plot	Fertil-izaion	Dry matter kg ha^{-1}	Spike No./m^2	Grain yield kg ha^{-1}	Test weight kg $L^{-1}10^2$	Protein %
1998	DRY	–K	4975a [a]	216.7a	1435a	75.1a	11.8b
	DRY	+K	5205a	213.6a	1420a	74.7a	12.6a
	IRR	–K	5384a	209.2a	1642b	79.2a	11.1a
	IRR	+K	5514a	205.1a	1935a	79.2a	11.3a
1999	IRR	–K	4293a	203.8a	1073a	78.1b	13.4#
	IRR	+K	3934a	205.8a	1091a	79.3a	12.9#
2000	DRY	–K	3383a	189.7a	1042a	78.5a	15.7#
	DRY	+K	3089a	181.6a	842b	77.5b	15.7#
	IRR	–K	4747a	207.2a	1629a	82.4a	13.9b
	IRR	+K	4933a	211.4a	1606a	82.5a	14.8a

a) Within years, plot and fertilization means followed by the same letter are not significantly different using LSD mean separation procedure; # = Significant N X P X K interaction.

Potassium uptake and its concentration in wheat plants are also affected by other nutrients, such as nitrogen (Beaton and Sekhon, 1985; Greenwood and Karpinets, 1997). Potassium in addition or in interaction with nitrogen and phosphorus affected protein content in the grain (**Tables 4** and **5**).

Table 5. Effect of NPK fertilization (kgha^{-1}) on wheat grain protein content (%)

Year	Plot	K	P 0				P 10			
			N 0	N 50	N 100	N 150	N 0	N 50	N 100	N 150
1998	DRY	0	10.3	12.1	13.0	13.4	10.9	10.6	12.0	12.3
	DRY	250	10.8	12.9	14.0	14.0	10.4	12.3	13.5	13.3
	IRR	0	11.0	11.0	11.7	11.0	10.7	10.8	11.4	11.4
	IRR	250	10.9	10.8	11.9	11.6	11.3	10.8	11.3	11.9
1999	IRR	0	12.8	13.5	14.0	14.9	12.0	13.2	13.8	13.4
	IRR	500	11.2	13.6	13.9	14.5	10.4	12.1	13.3	14.7
2000	DRY	0	13.8	15.9	17.1	17.5	13.7	14.4	15.3	17.9
	DRY	500	13.1	17.4	16.4	16.3	14.6	17.0	15.3	15.8
	IRR	0	13.3	13.2	13.6	14.4	14.6	13.7	14.1	13.9
	IRR	500	13.3	14.4	15.2	15.3	14.8	14.8	15.1	15.3

Potassium Top-dressing Application

Split application of potassium fertilizers on long season crops, such as grass crops that are harvested several times during the growing season, could be recommended. Late application could also decrease the severity of rust infection (Beaton and Sekhon, 1985). We tried to apply mono-potassium-phosphate (MKP, 2% in solution [200L/ha]) against stem rust (*Puccinia graminis*) without any success (not shown). In cereals, late application, at anthesis, of MKP delayed senescence of wheat leaves and increased grain yield (Benbella and Paulsen, 1998ab). This late top-dressing was tested over two years. In both field trials, there was no significant effect of MKP applications (**Table 6**). Plant development after MKP application was not changed, and the reported benefits due to potassium (Beaton and Sekhon, 1985; Benbella and Paulsen, 1998ab) did not appear in our experiments.

Wheat Quality

Potassium is known as the “quality nutrient” because of its important effect on quality factors such as size, shape, color, taste, shelf life, fiber quality, and other quality measurements. If the potassium percentage in dry matter declines

Table 6. Mono-potassium-phosphate fertilization at heading and wheat yield (MKP concentrations in 200 L ha^{-1})

Year	*MKP* %	*Grain yield* kg/ha	*Test weight* kg $L^{-1}10^2$	*Grain protein* %	*Grain P* g/kg	*Grain K* g/kg	*Grain weight* mg
1999	0	2587	76.8	13.9	2.90	3.67	27.0
	1.3	3075	77.1	13.7	2.93	3.62	29.1
	4	2770	77.4	13.9	2.90	3.75	28.1
2000	0	1961	82.9	13.1	2.51	2.62	37.7
	2.5	2055	82.8	13.2	2.52	2.77	37.3

to less than 1% then more nitrogen that accumulated by plant is not presented as protein (Leigh and Wyn Jones, 1984). Several indications exhibit the increase in baking quality with potassium application (Kemmler, 1983; Usherwood, 1985). The effect of potassium on quality was tested indirectly, by testing grain protein or N content, amino acid translocation to grains, protein quality and composition, water absorption, Zelany sedimentation, etc. (Usherwood, 1985). A simple model shows that the effect of higher potassium levels on quality could be related to a parallel increase in grain protein content (Blevins, 1985). We tested loaf volume of 95 samples, from different experiments, for baking quality determination. The quality ranged from very poor (1400 cc) to excellent (2410 cc). Although protein content is known as the main factor affecting loaf volume, only a low correlation was found (r = 0.44). Excellent flour, 2033 cc, contained only 10.4% protein, while poor quality, 1700 cc, contained 14% protein. Therefore, multi-variance regression analysis was carried out to identify the factors that affect loaf volume. Experimental treatment, yield (quantity and test weight), grain mineral content (NPK percentage and quantity) could be these factors. It was found that the ratios N/K and K/P in the grains and the P and K fertilization treatments were the factors, as follows:

Loaf volume (cc) = 1822 + 77.6 N/K – 6.69 P – 271.1 K/P + 0.21 K (R^2 = 0.43; p(F) < 0.0001; P treatment 0 or 10 kg/ha; K treatment 0 or 250 kg/ha)

The nitrogen to potassium ratio explains about 70% of the variance. Hence, it emphasizes other factors affecting baking quality, not only nitrogen. It was shown that nitrogen and potassium are accumulated in the same ratio, and this ratio is related to seed protein content (Blevins, 1985). In contrast, our results demonstrate that this ratio is not constant, and could be attributed to growth conditions. A high ratio could result from superior conditions, high

N translocation to grains, high starch accumulation and therefore potassium dilution. In other cases, for example as a result of drought, potassium does not return to the roots, therefore is not diluted, and a low ratio is present. That potassium and phosphorus are involved in baking quality is in agreement with previous works that exhibit direct or indirect effects of K and P on seed storage protein composition or other quality parameters (Bonfil *et al.*, 1997; Usherwood, 1985).

Conclusions

The conclusions of this paper are from fields where potassium was not a limiting factor for growing wheat. Despite a lack of fertilization over long periods, soils maintained a high buffer capacity of potassium and could supply enough potassium to wheat growth. Potassium uptake by wheat was always lower than the quantity that the soil could supply, and never limited wheat growth. Potassium concentration was at least 1%, and the cytoplasm potassium content was at least 140 mM. Difference in K uptake must have been related to differences in total dry matter accumulation and not to potassium application. Pre-sowing application of 500 kg K per ha had no effect on wheat yield, except some effect on grain protein content. Top-dressing of MKP had no significant effect on wheat growth, yield, and stem rust infection. Therefore, fertilization recommendation should not include potassium application for wheat. However, in reference to baking quality, it was found that potassium and phosphorus in addition to nitrogen are factors that affect wheat quality. The ratios N/K (main factor) and K/P in the grains and the P and K fertilization treatments affected loaf volume. Therefore, keeping continuous control of K uptake must be done to prevent a reduction in baking quality in the future.

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