International Workshop on Soil Potassium and K Fertilizer Management

Potassium and Water Interaction

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- 14 November 2006

Potassium nutrition of crops

- Unlike N and P, K exists in plant as an ion, and does not form stable complexes.
- Potassium is characterized by high mobility in plants at all levels (cells, tissues, long-distance transport) , which is easily transported from roots to shoots.
- Potassium transfers easily with growth center and is preferentially distributed in younger tissues.

Function of potassium nutrition

- Enzyme activation;
- Increasing photosynthesis and carbohydrate synthesis and translocation of photosynthate and carbohydrate
- Protein synthesis
- Improving the tolerance of plants to stress
- Suitable amount of K can improve crop quality

Enzyme activation

- There are more than 60 enzymes which either completely depend on or are stimulated by K^+, e.g. ATPase, pyruvate kinase, 6-phosphofructokinase
- K^+ activates enzymes by inducing conformational changes in the enzyme protein.

Enzyme activation

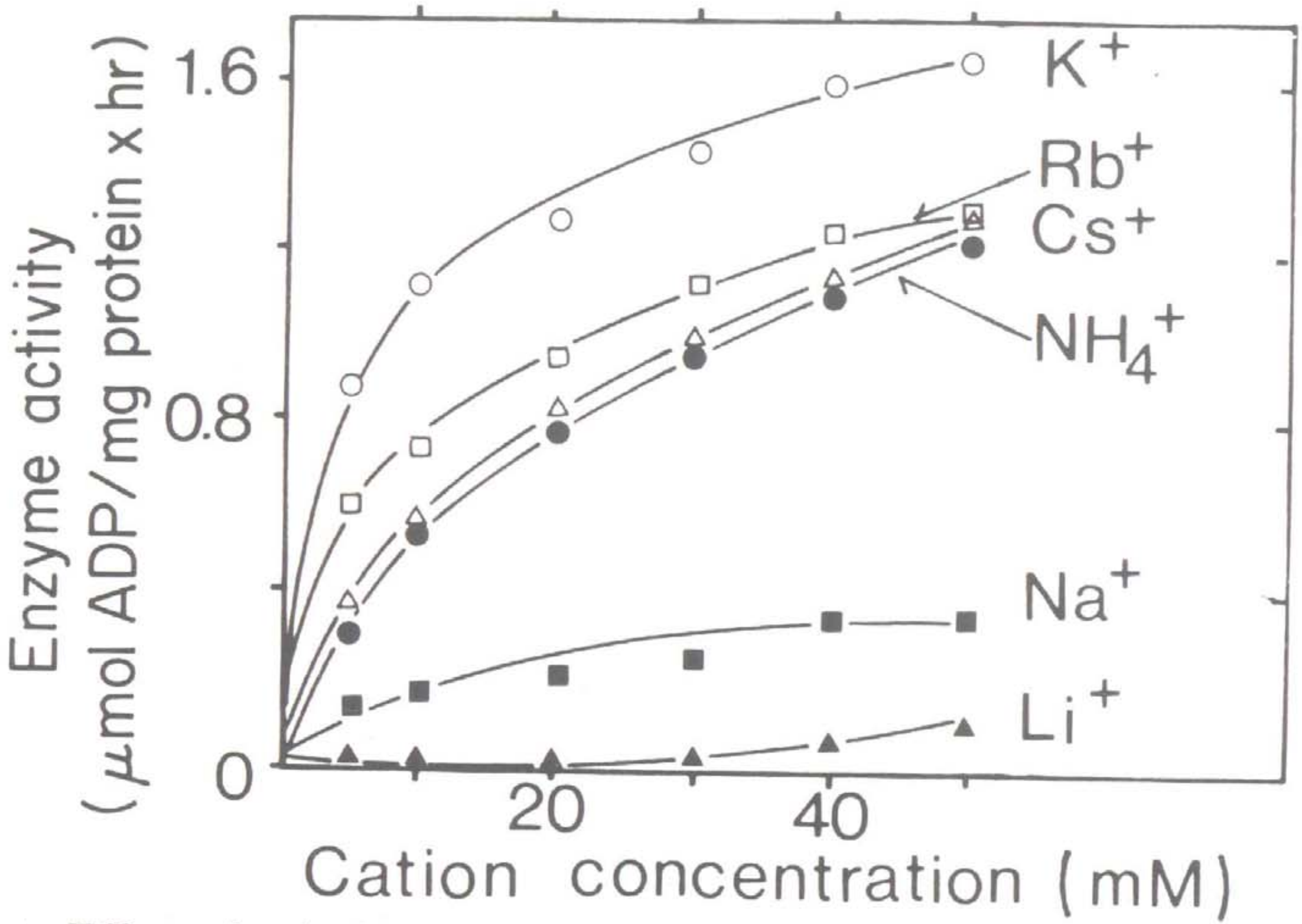


Fig Effect of univalent cations (as chlorides) on the activity of ADP-glucose starch synthase from maize. (Nitsos and Evans, 1969.)

Improving the tolerance of plants to stress

- Drought;
- High temperature;
- Cold;
- Disease and pest;
- Salt stress;
- Lodging

Relationship between K supply and tuber yield, K content in leaves and percentage of leaves damaged by frost in potato

K supply (kg/ha)	Tuber yield (t/ha)	K content in leaves (mg/g)	Percentage of foliage damaged by frost (%)
0	2.39	24.4	30
42	2.72	27.6	16
84	2.87	30.0	7

Suitable amount of K can improve crop quality

- **Increasing protein and ammonia acid composition**
- **Increasing sugars and starch content ;**
- **Enhancing vitamins in vegetables;**
- **Delaying storage period;**
- **Improving commercial quality;**

Effect of K application on amino and sugar contents in barley (%)

Treatments	Cysteine (Cys) content	Methionine (Met) content	Tyrosine (Tyr) content	Tryptophan (Try) content	Starch content	Soluble content
NP	0.18	0.14	0.36	0.121	44.9	9.36
NPK	0.20	0.20	0.42	0.135	46.5	10.40

Effect of K application rates on protein content in rice seed

K_2O (kg/ha)	Protein content (%)	
	Early rice	Late rice
0	9.77	8.70
30	10.33	9.31
60	9.95	9.68
120	10.08	9.03
180	10.33	9.11

Effect of potassium sulfate on tomato fruit quality

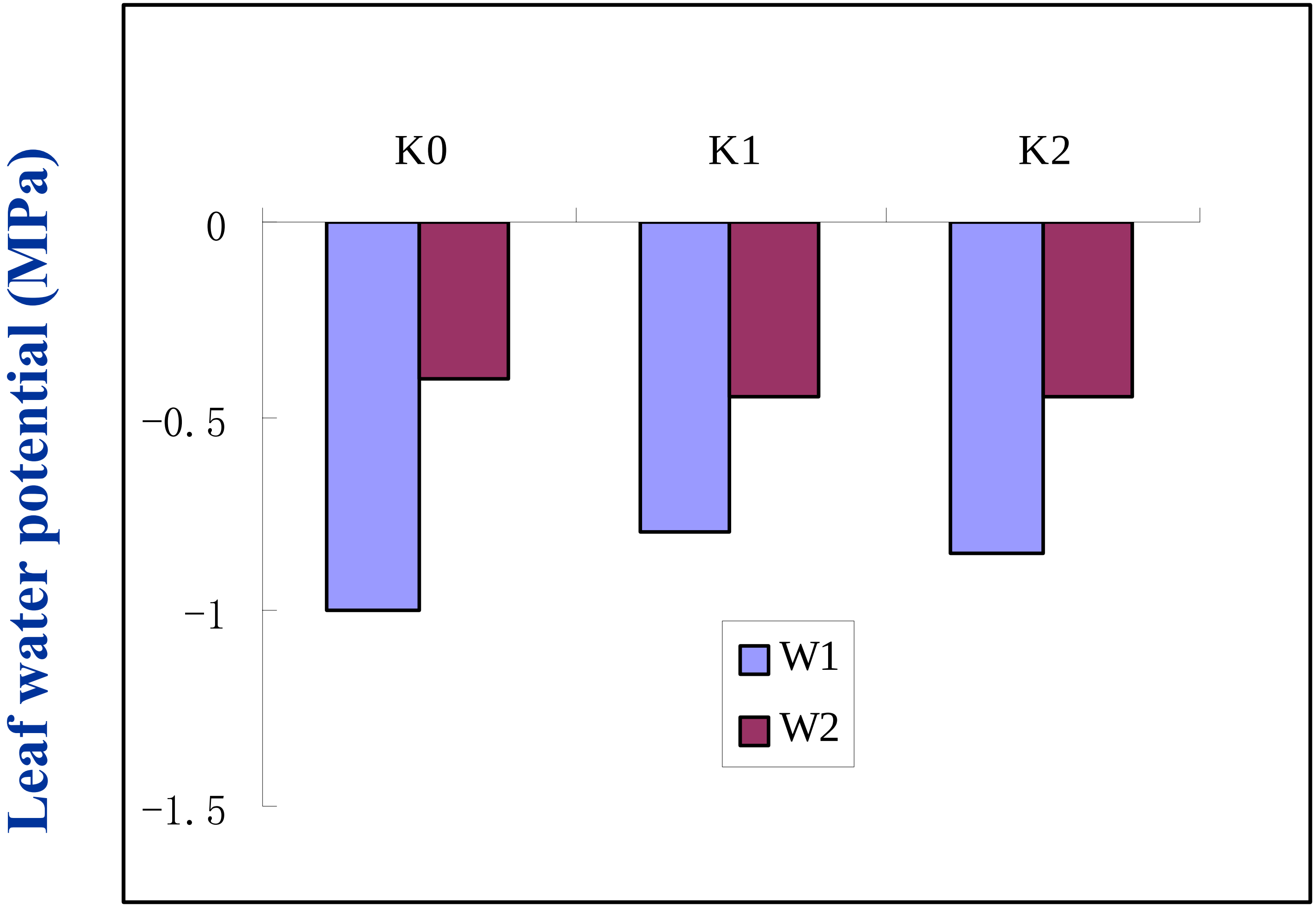
K_2O (kg/ha)	Sugar content (%)	Vc (mg/100g)	Total organic acids (%)
0	2.37	12.36	0.070
307.5	3.17	19.75	0.072
562.5	3.32	17.56	0.071
870.0	3.27	18.36	0.073

Potassium increases drought resistance and water use efficiency in crop

- Reducing leaf osmotic potential and increasing turgor in drought treatment
- Increasing relative water content
- Increasing leaf water potential
- Increasing bound water content
- Increasing water use efficiency

K application reduces leaf osmotic potential, but increases turgor pressure in drought treatment in winter wheat

Irrigation level	K applied rates (g/kg)	Osmotic potential (Mpa)	Turgor (Mpa)
Drought (W_1) 35-45% of field capacity	K_0 (0)	-1.80a	0.66c
	K_1 (0.15)	-1.92bc	0.98b
	K_2 (0.30)	-1.82ab	0.82b
Conventional irrigation (W_2) 65-75% of field capacity	K_0	-1.86abc	1.41a
	K_1	-1.90abc	1.40a
	K_2	-1.88abc	1.36a

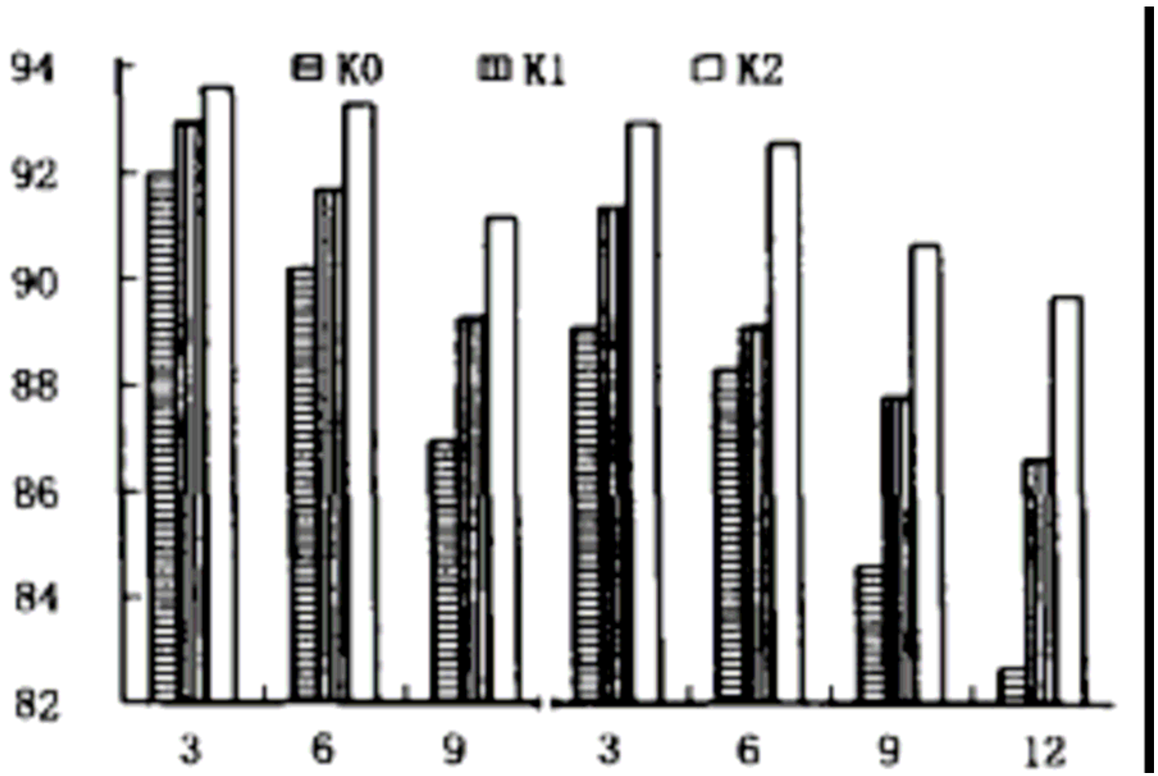


Potassium increases leaf water potential in drought treatment in winter wheat

K application reduces leaf water potential and osmotic potential , but increases turgor pressure, tuber water and K contents in potato

Items	K applied level (g K/kg soil)		
	K_1 (0.125)	K_2 (0.50)	K_3 (1.00)
Water potential (Mpa)	-0.09	-0.16	-0.20
Osmotic potential (Mpa)	-0.63	-0.73	-0.79
Turgor (Mpa)	0.53	0.59	0.60
Water (g/g dry matter)	2.9	3.6	3.7
K^+ (mmol/L cellular solution)	93	154	179

Potassium increases leaf relative water content in tobacco



Leaf relative water content(%)

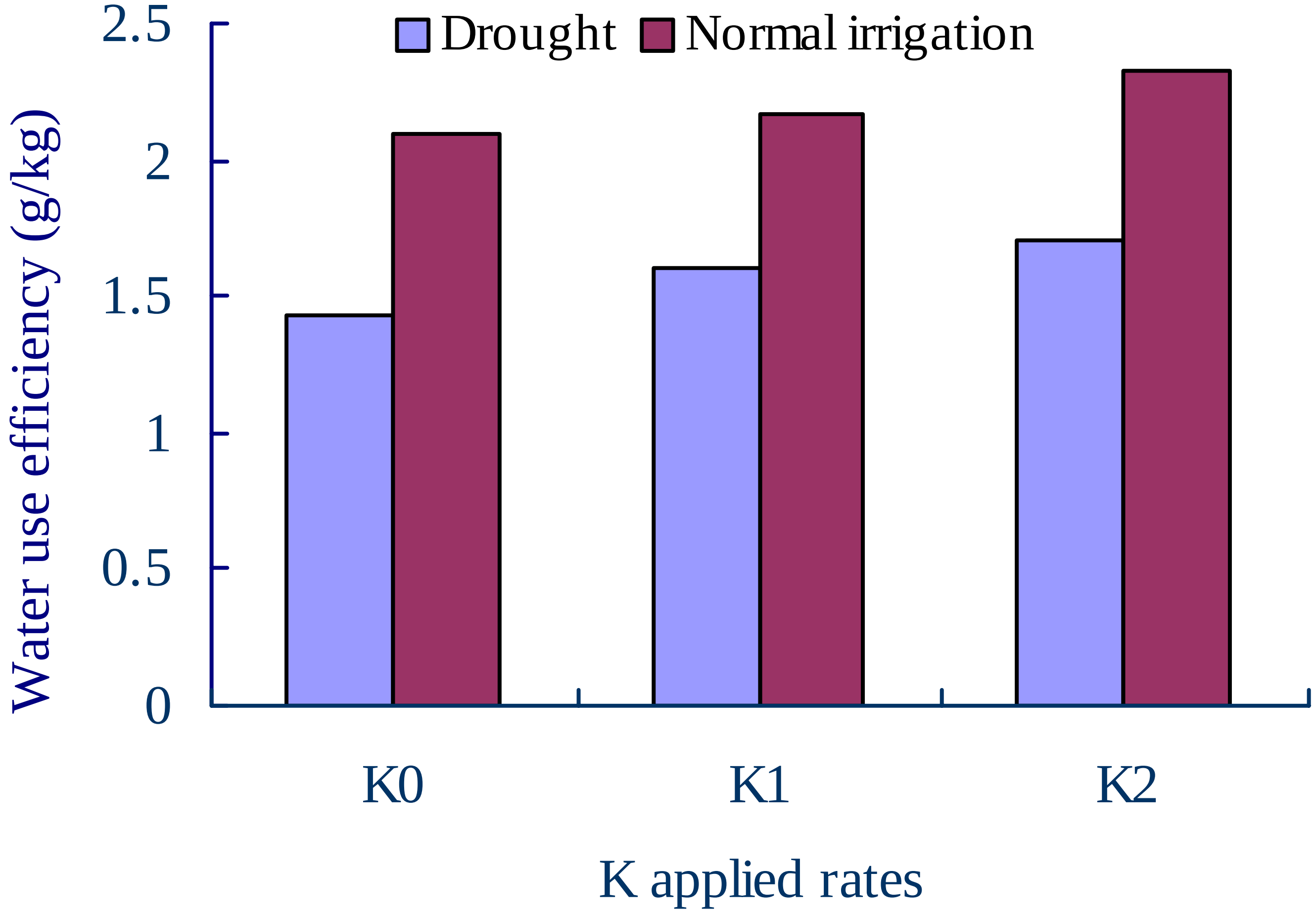
Days after drought

1st Drought   2nd Drought after rewatering

Potassium increases bound water potential in soybean

Part	Treatment	Bound water content (%)
Leaf	K supply	3.1
	CK	2.1
Root	K supply	2.0
	CK	1.0

Potassium increases water use efficiency of winter wheat



The mechanism of potassium increasing drought resistance and water use efficiency

1. Maintaining normal cell structure and promoting the development of translocation tissues

- Improving chloroplast structure, promoting photosynthesis
- Increasing the thickness of cell wall
- Increasing the thickness and size of stem catheter
- Improving leaf vessel tissues

The mechanism of potassium increasing drought resistance and water use efficiency

2. Safeguarding enzymes activity in cells

Potassium can be beneficial to adjust superoxide dismutase (SOD) activity in plants, then mitigate the injury of free radical of active oxygen derived from drought stress to plasm membrane and maintain the integrality of cell membrane, as a result, applied K can reduce the efflux of cell substances. Thus potassium could strengthen drought resistance of the plant.

Potassium increases leaf superoxide dismutase (SOD) activity in tobacco

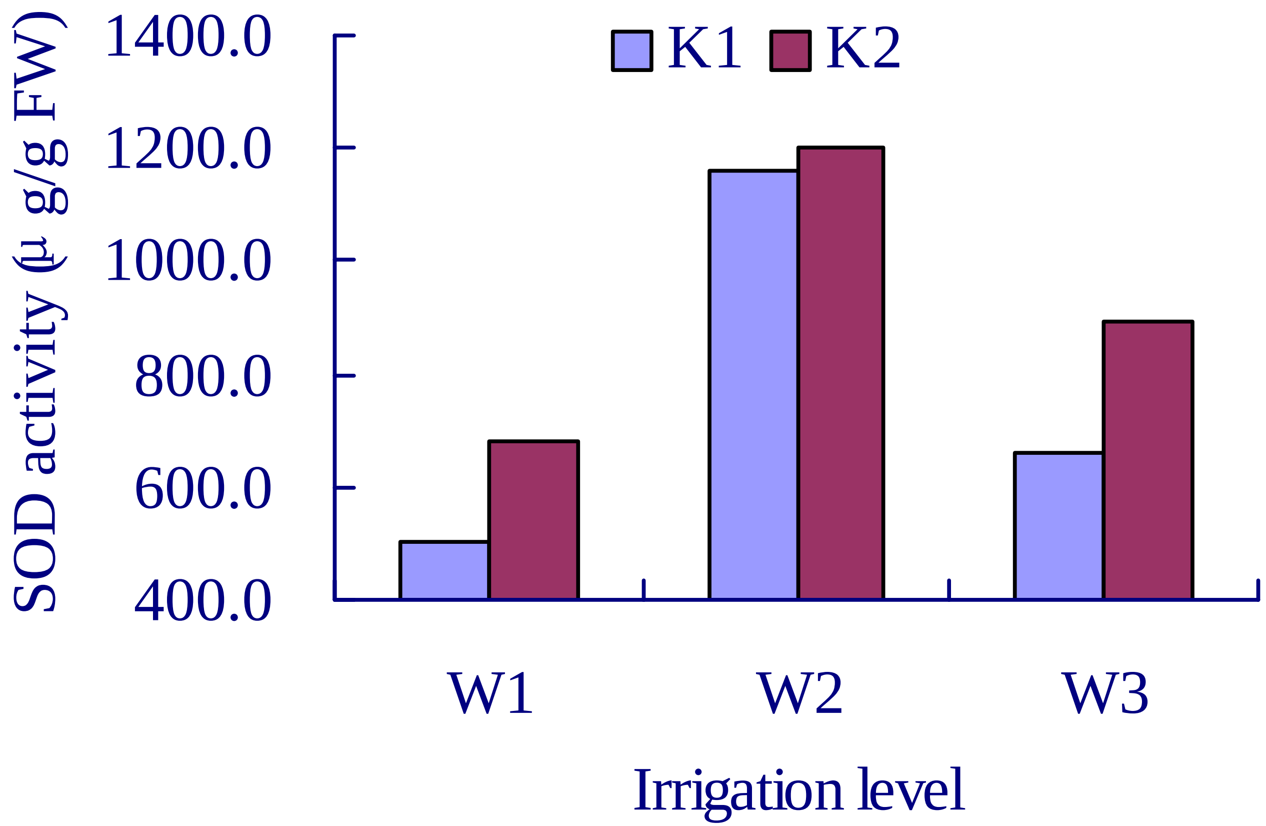
W_1 70-80% θ_f (θ_f field capacity)

W_2 30-40% θ_f

W_3 50-60% θ_f

K_1 0.3 g/kg

K_2 0.6 g/kg



Effect of applied K on permeability of leaf cell membrane induced by drought in tobacco (expressed as relative electric conductivity, μ s/cm/ml)

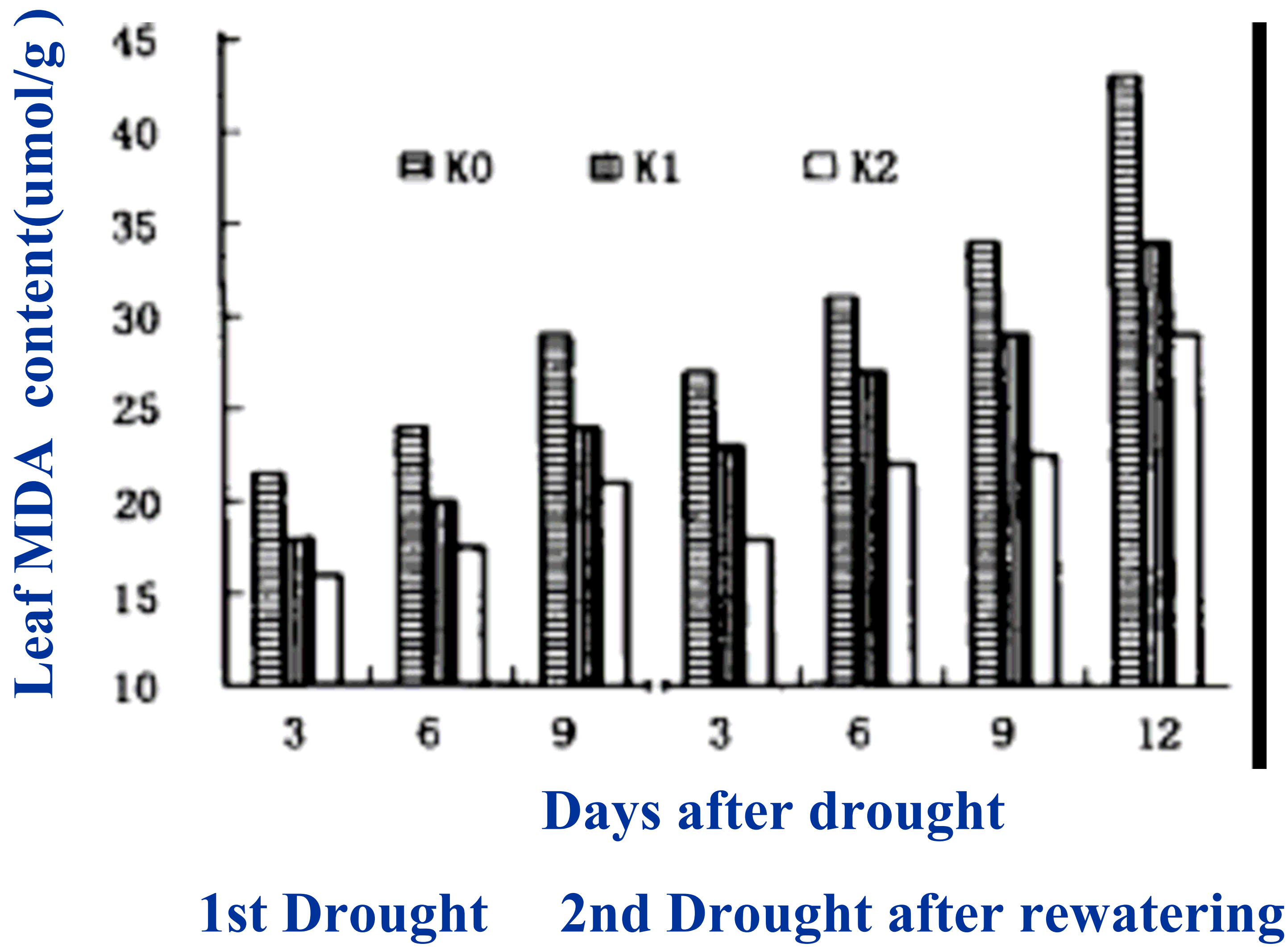
K level (g/kg)	First drought		Second drought after rewatering		
	6 d	9 d	6 d	9 d	12 d
K_0 (0)	2.67	3.25	2.61	3.43	5.04
K_1 (0.33)	2.49	2.91	2.37	3.09	4.49
K_2 (0.67)	2.33	2.60	2.10	2.51	3.40

The mechanism of potassium increasing drought resistance and water use efficiency

3. Adjusting proline, malondialdehyde (MDA) and internal hormone content in plants

- **Potassium increases the accumulation of leaf proline content, then strengthen the drought resistance of the crops**
- **Potassium can suppress the increase of leaf MDA content induced by drought**
- **Water stress reduces the growth-stimulating hormone level of crop, e.g CTK , but increases the ABA and ethylene content, and then slow or suppress crop growth. But potassium can maintain the balance of internal hormone in plants**

Potassium can suppress the increase of leaf malondialdehyde (MDA) content induced by drought in tobacco



The mechanism of potassium increasing drought resistance and water use efficiency

4. **Increasing osmoregulation**

- **K^+ is the dominant osmotic substances**

Influence of K supply on osmotic substances in wheat (mg/g sap)

Irrigation level	K level (g/kg soil)	K^+	Soluble sugar	Na^+	Ca^{2+}	Mg^{2+}
Drought (W_1) 35-45% of field capacity	K_0 (0)	6.15d	1.26bc	0.17b	1.46a	0.65a
	K_1 (0.15)	7.15c	1.58ab	0.15b	1.40a	0.50c
	K_2 (0.30)	7.80bc	1.45b	0.14b	1.28ab	0.47cd
Conventional irrigation (W_2) 65-75% of field capacity	K_0	6.55d	1.34b	0.27a	0.95cd	0.57b
	K_1	8.27ab	1.40b	0.15b	1.08bc	0.42d
	K_2	8.87a	1.98a	0.16b	0.88d	0.36e

Cell extension is the consequence of the accumulation in the cells of K^+

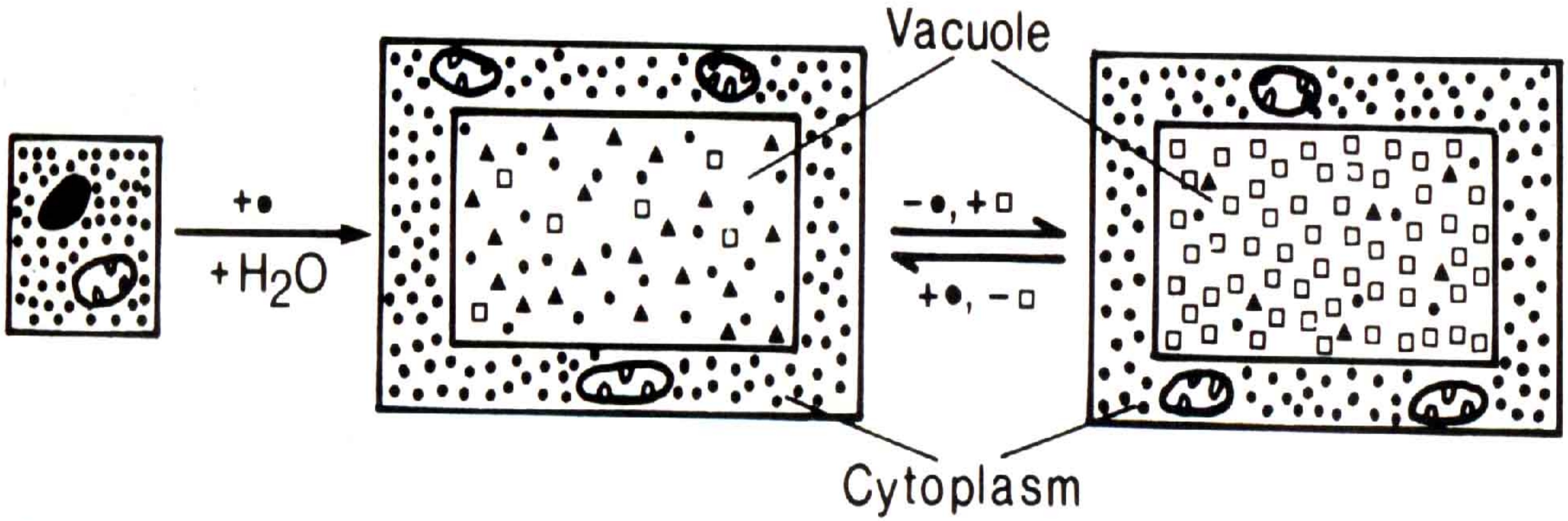


Fig. 8.24 Model of the role of potassium and other solutes in cell extension and osmoregulation. Key: ●, K^+; □, reducing sugars; sucrose, Na^+; ▲, organic acid anions.

The mechanism of potassium increasing drought resistance and water use efficiency

5. Increasing the sensitivity of stomatal movement and regulating and controlling transpiration

- The lower water loss of plants well supplied with K is due to a reduction in transpiration which on not only depends on the osmotic potential of the mesophyll cells but is also controlled to a large extent by the opening and closing of stomata

Stomatal movement

- In most species K^+ has the major responsibility for turgor changes in the guard cells during stomatal movement
- An increase in the K^+ concentration in the guard cells results in the uptake of water from the adjacent cells and a corresponding increase in turgor in the guard cells and thus the stomatal opening
- K supply can also lead to the closing of stomata quickly in a few minutes when strong dry wind and drought happen.

Effect of K supply on leaf stomatal resistance of cotton (s)

Treatment	First leaf (s)	Second leaf (s)	Third leaf (s)
-K	6.95	6.71	6.18
+K	12.69	11.27	11.63

Sampling leaves from the second branch

The mechanism of potassium increasing drought resistance and water use efficiency

6. Increasing the metabolism of chemical compound and energy, such as the increasing of photosynthesis and protein synthesis, promoting plant growth

Photosynthesis and and photosynthate translocation

- In higher plants K^+ affects photosynthesis at various levels
- Enhancing chlorophyll synthesis
- Improving chloroplast structure
- Increasing CO_2 fixation
- Improving photosynthate translocation

Influence of the antibiotic valinomycin and K on the rate of CO_2 fixation in isolated intact spinach chloroplasts

Treatment	Rate of CO_2 fixation (mol/mg chlorophyll/h)	Relative percentage (%)
Control	23.3	100
100 mM K^+	79.2	340
1 M valinomycin (颉氨霉素)	11.0	47
1 M valinomycin + 100mM K^+	78.4	337

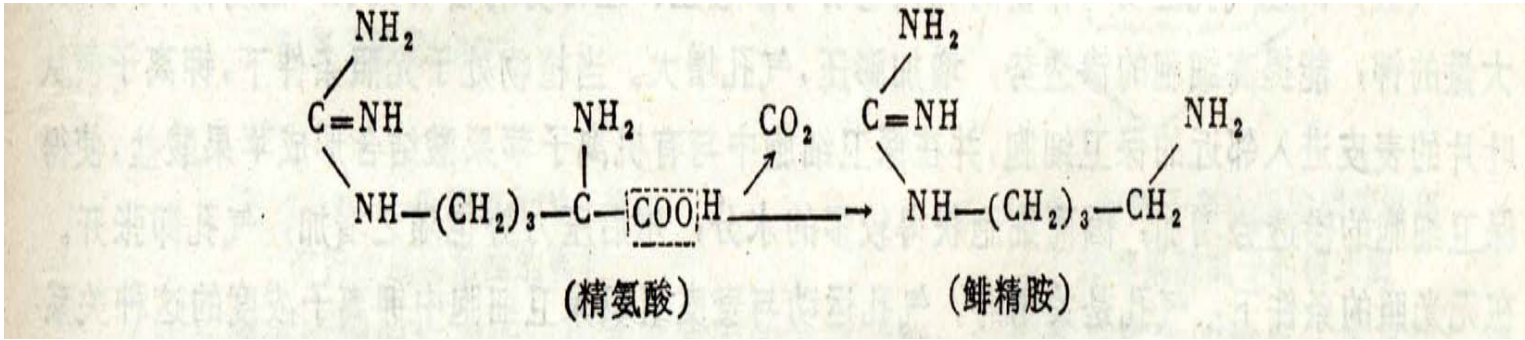
Translocation of C-14 labelled photosynthates in sugarcane with a low and high K supply (total label=100%)(Hartt, 1969)

Treatment	% of total labelled	
	+K	-K
Fed blade	54.3	95.4
Sheath of fed leaf	14.2	3.9
Joint of fed leaf	9.7	0.6
Leaves and joints above fed leaf	1.9	0.1
Stalk below joints of fed leaf	20.1	0.04

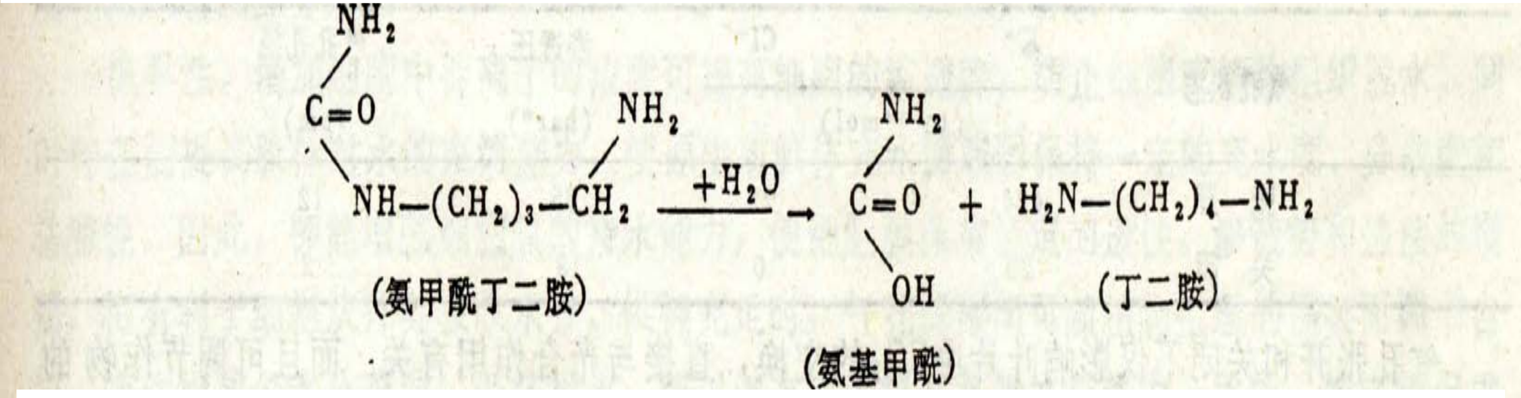
Protein synthesis

- It is now well established that K^+ is required for protein synthesis in higher plants
- K^+ is involved in several steps of the translation process, including the binding of tRNA to ribosome

The accumulation of soluble nitrogen compounds (aa, amide, and nitrate) when K^+ is deficient



Arginine Agmatine



Carbamylputrescine Carbamic acid Putrescine

K nutrition function on protein synthesis shows a role on nitrogen fixation

Effect of K on alfalfa nodules

K supply (811 kg K_2O/ha)	Number of nodules/plant	Weight of fresh nodule (mg/plant)	Protein of nodule (mg/g nodule)
CK	41.7	53.3	70.0
K_2SO_4	111.3	140.8	32.3
KCl	93.4	86.8	21.3

Effect of P and K on soybean growth and nodules

P_2O_5 (kg/ha)	K_2O (kg/ha)	Number of nodules/plant	Weight of fresh nodule (g/m^3 soil)	Yield (t/ha)	Protein production in seed (kg/ha)
0	0	35	16	1.68	717
134	0	59	33	1.75	739
0	134	79	46	3.16	1232
134	134	114	85	3.70	1344

Influence of soil water on potassium use and potash fertilizer effect

- Affecting soil potassium bio-availability
- Affecting the transforming of soil potassium
- Affecting K fertilizer efficiency

Soil water affects soil potassium bio-availability

- K^+ at the root surface removed by root absorption is mainly replenished to this site by K^+ movement to the root by diffusion through the soil.
- Soil water affects soil solution volume and the movement of K^+ ion, then affects K^+ diffusion .
- The decrease of soil water content reduces the cross sectional area for diffusion and increases the tortuosity of the diffusion path, then reduces the diffusion rate and distance of K^+ ion and K uptake.

Soil water affects soil potassium bio-availability

- **When soil water content drops from 23% to 10%, the diffusion coefficient reduces from 10^{-6} mm/s to 5×10^{-7} mm/s.**
- **When soil water content drops from 25% to 15%, the diffusion distance in one day of K fertilizer reduces from 12 mm to 6 mm.**
- **The decrease of soil water reduces the K concentration and uptake in winter wheat (see the following table)**

Effect of different water level on leaf K content of tobacco in different growth period (%)

θ_f is field capacity

Water treatment	Days after transplanting				
	30 d	40 d	50 d	60 d	70 d
$50\%\theta_f$	4.1	3.3	2.5	2.4	1.9
$60\%\theta_f$	4.7	4.2	2.8	3.6	2.5
$70\%\theta_f$	5.4	4.2	3.2	3.2	2.5
$80\%\theta_f$	4.3	4.0	2.7	2.5	2.2

Effect of different water level on leaf K uptake of tobacco in different growth period (g/plant)

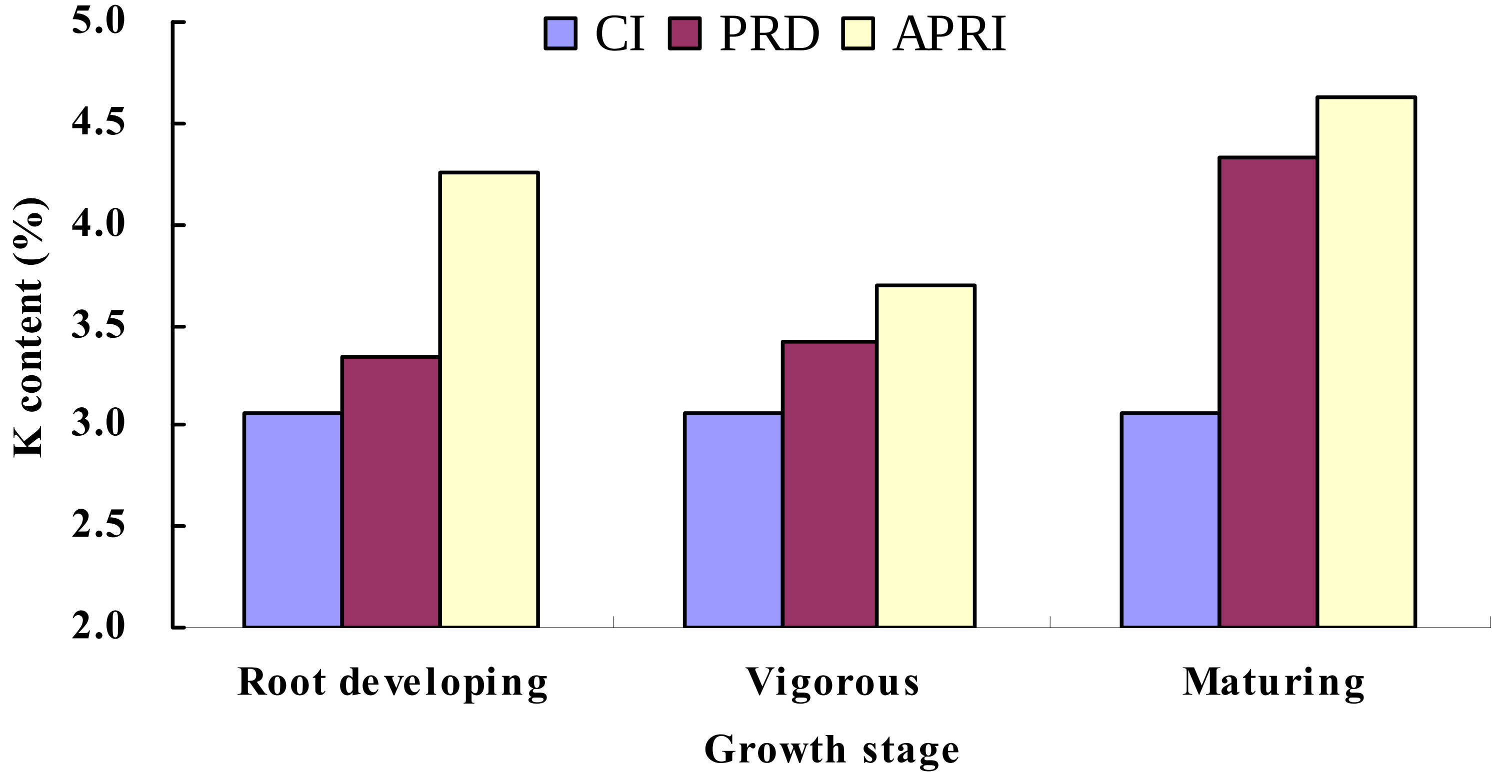
θ_f is field capacity

Water treatment	Days after transplanting				
	30 d	40 d	50 d	60 d	70 d
50%θ_f	0.60	0.99	1.76	1.79	1.49
60%θ_f	0.79	1.25	2.22	2.35	2.38
70%θ_f	1.01	1.51	2.79	3.28	3.32
80%θ_f	0.69	1.10	2.06	2.22	1.96

Effect of different water treatment during the growth stage on leaf K content of tobacco grown in cinnamon soil (%)

Water treatment during the days after transplanting		Lower leaves	Middle leaves	Upper leaves
30-60 d	61-90 d			
80%θ_f	80%θ_f	3.83	4.17	3.76
70%θ_f		3.51	4.34	3.67
60%θ_f		3.81	4.58	3.81
80%θ_f	70%θ_f	3.23	3.39	2.87
70%θ_f		3.38	4.04	3.46
60%θ_f		3.12	4.34	3.61
80%θ_f	60%θ_f	3.76	4.16	3.48
70%θ_f		3.42	3.57	3.77
60%θ_f		3.12	3.43	3.23

Effect of different irrigation method during the growth stage on leaf K content of tobacco (%)



Effect of soil tension and bulk on K uptake of tobacco (K_2O g/plant)

Soil tension (mbar)	Lower soil bulk (1.15 g/cm^3)	Higher soil bulk (1.50 g/cm^3)
10-50	2.91 a	1.95 c
100-200	2.63 b	2.80 a
250-350	3.00 a	2.50 b
400-600	2.61 b	1.80 c
600- 800	2.27 c	1.44 d

K supply can increase the diffusion of K^+ and K concentration and uptake in winter wheat under drought condition, but this may increase the cost of fertilizer and sometimes can not effectively increase K uptake under severe drought condition

Irrigation level	K applied rates (g/kg)	K concentration (mg/g DW)	K uptake (mg/pot)
Drought (W_1) 35-45% of field capacity	K_0 (0)	25.7e	57.7ef
	K_1 (0.15)	31.6c	77.5de
	K_2 (0.30)	35.1b	91.6d
Conventional irrigation (W_2) 65-75% of field capacity	K_0	28.0d	181.8c
	K_1	35.8b	241.5b
	K_2	38.1a	282.2a

Soil water affects the transforming of soil potassium

- In north China, K fertilizer is easily fixed by soil. Four soils from Anhui province indicated that the maximal K fixation in soils occurred in two days, with K fixation rate of 13.4- 37.2 % in these soils. And alternate wetting- drying treatment increased K fixation in soils.
- In soil grown tobacco, K fixation rate is 72%～82% when applied K fertilizer after a week.

Effect of alternate wetting- drying treatment on K fixation in four different soils from Anhui province

Added K is 800 mg/kg

Soils	Conventional watering		Alternate wetting-drying treatment	
	The amount of K fixed (mg/kg)	K fixation percentage (%)	The amount of K fixed (mg/kg)	K fixation percentage (%)
Lime concretion black soil	257.2	32.2	502.3	62.8
Fluvoaquic soil	297.4	37.2	453.3	56.7
Yellow cinnamon soil	250.1	31.3	557.2	69.7
Paddy soil	107.3	13.4	205.6	25.7

Soil water affects the transforming of soil potassium

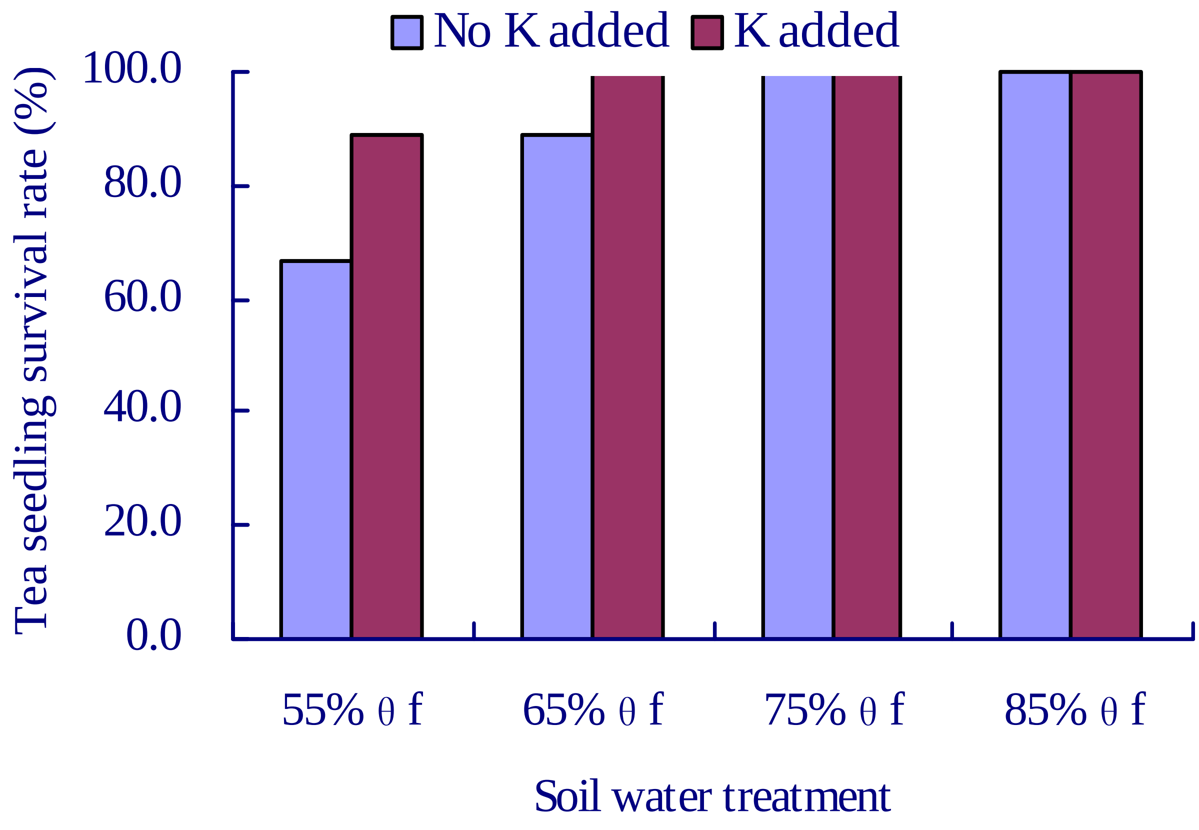
- **In south China, K fertilizer is easily leached from the soil because of high rainfall, with K leaching loss of 15.37%–26.33% in the soil grown tobacco.**

Soil water affects the K fertilizer efficiency

- Soil water content can affect the K fertilizer efficiency.
- In different rainfall years, the effect of K fertilizer is different.

Effect of K application on the survival rate of tea seedling

No seedling was survived at 45% θ f irrespective of applied K or not , θ f is field capacity



Effect of rainfall on K fertilizer efficiency in the period of corn growth (Younts, 1971)

Rainfall (mm)	Yield (t/ha)		Yield increase by K (t/ha)
	NP	NPK	
202 (Deficit)	5.95	8.10	2.45
448 (Moderate)	9.30	9.80	0.50
655 (Excess)	5.71	8.73	3.02

Conclusion remarks

- Rational application of K fertilizer can increase the drought resistance, crop yield and water use efficiency.
- Soil water affects the bio-availability and transforming of soil potassium, and then affects crop K uptake and K fertilizer efficiency. Therefore the efficient effect of K application on K uptake and K fertilizer efficiency should combine with rational irrigation.

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