Optimizing Crop Nutrition

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Editorial

Dear Readers,

Prices of food crops shot up and then fell quickly in 2008, but with favorable climatic conditions in many parts of the world, a record cereal harvest is expected. At IPI, we believe that another important reason for this record harvest was that many farmers invested in their production systems while commodity prices were high.

However, high prices for food crops do not change the basic requirement to use resources efficiently. Fertigation is one of the advanced tools for achieving large savings of both water and nutrients and, in recent years, IPI has initiated several field experiments with fertigation systems, focusing on potassium management. In this *e-ifc* edition we provide a detailed report of our IPI-NATESC apple fertigation experiment in China's Shandong Province.

The Food and Agriculture Organization (FAO) declared 2008 the "International Year of the Potato" (IYP). It was a good year for this humble crop as, with high cereal prices, demand for potato increased and it has now become a more affordable staple in many countries. Potato is well known as a "potassium lover" and, in this edition of *e-ifc*, you will find a feature dedicated to this important crop.

At the start of this new year, we look forward to the challenges of 2009 and hope that our readers experience timely and sufficient rains, optimum climatic conditions, relatively few attacks of pests and diseases, and of course, good market prices.

On behalf of IPI, I wish our readers a fertile and productive 2009.

I wish you all an enjoyable read.

Hillel Magen

Director

Plentiful vegetables in street market in Haryana, India. Photo by IPI.

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I Fertigation management in young apple trees in Shandong, China

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Preparing and installing the fertigation system in the young apple orchard. Penglai, spring 2004. Photo by IPI.

Introduction

Apple production in Shandong Province, eastern China, occupies 305,000 ha, approximately 20 per cent of the country's total apple area in 2007. Average yields in the region were 23.8 mt/ha, higher than the national average for the same year (14.2 mt/ha). Recently, a large area has been developed for apple cultivation in provinces of the north-west China (Gansu, Shaanxi, Ningxia and more).

The leading varieties in the Shandong Province are Red Fuji, Red General, Gala and Jonagold. The typical irrigation and fertilization management practices used in Shandong for growing apples include: furrow and flood irrigation, application of manure and basal fertilizer in grooves encircling the trees after harvest or in the following early spring, and top-dressed fertilizer application broadcast with three or four splits during the growing period of the tree. These traditional methods of irrigation and fertilization make water and fertilizer use inefficient.

In irrigated horticultural production systems, precision in the application of water and nutrients can be achieved by fertigation (Scaife and Bar-Yosef, 1995; Bar-Yosef, 1999; Haynes, 1985; Neilsen *et al.*, 1999). Deciduous fruit trees are typically characterized by a low rooting density, several orders of magnitude lower than that of herbaceous plants (Atkinson, 1980); apple trees on dwarfing rootstocks have particularly low-density root systems (Neilsen *et al.*, 1997). Consequently, increased efficiency in nutrient supply requires timely and precise placement with high retention in the main rooting zone (Neilsen and Neilsen, 2008).

Parchomchuk *et al.* (1993) reported that fertigating with acidifying fertilizers through a drip system can lead to leaching and hence depletion of K and other soluble bases to a depth of 30 cm beneath the emitter after only a few years of application. Potassium can be effectively applied via fertigation, using various K sources, such as potassium chloride (KCl, or MOP), potassium sulfate (K_2SO_4, or SOP), potassium nitrate (KNO_3) and mono-potassium phosphate (KH_2PO_4, or MKP). Selection of K salt is based on market availability, price, effect on salinity, solubility and the application system used (Kafkafi *et al.*, 2001). Simple tables for calculating N, P and K fertigation based on low concentration solutions made in field conditions are available (Lupin *et al.*, 1966). Daily K fertigation from mid-June to mid-August (northern hemisphere summer) at 15 g/tree/yr maintained a higher K concentration in the soil solution as well as leaf K concentrations above deficiency levels. Fruit yield, fruit size, titratable acidity and red color at harvest all increased in the apple cultivars "Gala", "Fuji", "Fiesta", and "Spartan" (Neilsen *et al.*, 2004b). In these experiments reported by Neilsen it appears that the form of K fertilizer has little effect on tree response.

Fertigation of apples is widely practiced throughout the world. In Canada, Israel and other countries where apple receives irrigation, fertigation is a common practice for supplying nitrogen and potassium, and to a lesser extent, phosphorus.

The aim of the IPI-NATESC experiment reported here was to evaluate the effectiveness of fertigation with dry soluble nitrogen and potassium fertilizer in an apple orchard under the brown soil (cambisols) conditions in Shandong province. This paper presents the results of three years (2004-2007) of fertigation in young apple trees starting one year before taking the first commercial yield. The objectives of the work were to test the effect of the fertigation system in its ability to deliver optimal amounts of water and nutrients and the effect of various amounts of nitrogen, and potassium supplied as dry and fertigated nutrients on tree development, and yield and quality of apples.

Materials and methods

Experimental site

A full fertigation system was installed at the Penglai orchard, which is located in the east of Shandong province, near Yantai city. This city lies on the southeastern coast of the Bohai sea, 500 km to the north-east of Jinan, the

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The control head of the fertigation system used in the experiment. Each treatment was operated through a separate water and nutrient supply. Photo by IPI.

capital of the Province (see map). The climate in the region is defined as "a monsoon climate of the temperate zone", the annual average temperature is 12°C, with an average rainfall of 642 mm/yr, an average evaporation rate (class A pan) of 1,140 mm/yr, and a frost-free period of approximately 200 days and 2,826 hr of sunshine per year.

The apple variety used in the study was "red general" (arbor), originating from Japan. Trees were planted in the year 2000 and the experiment begun four years later. The density of planting was 3.0 m x 5.0 m, with a total of 667 trees/ha. Each replicate consisted of five trees, and buffer lines and trees were used between the replicates.

The soil type is loamy and classified as an "initial brown earth" on light sloping land, 80-90 cm deep. The following physiochemical properties were recorded: field capacity of 21.5 per cent (w/w), bulk density 1.41 g/cm^3 and CEC of 13.7-21.6 cmol/kg soil. Available nutrient contents, soil organic matter (OM) and pH before the experiment started are given in Table 1.

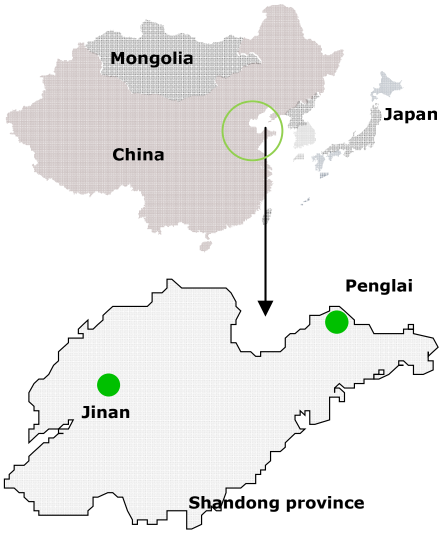
Farmyard Manure (FYM)

FYM (composted poultry litter) was added to all the treatments at 1,700 kg/ha every year, in spring or autumn. The analysis of the applied manure is shown in Table 2.

Irrigation and quality of water

The irrigation system used was a "micro irrigation system" (MIS) designed especially for this experiment so that each treatment was operated separately and monitored at the control head (see photo left). The water head of the system was typically 15 m, which allowed delivery of the precise amount of water and nutrients to each treatment. The jet emitters were positioned along the line of trees, one jet near each tree with a discharge rate of 70 L/h. The wetted diameter was 3.4 m in 2004 which was extended to 4m in 2005 and 2006 because of the increase in tree crown.

Irrigation started in early April and ended at mid July; at this time, irrigation was supplied in order to reach field capacity (21%, w/w). Irrigation quantity and scheduling was made in accordance with the daily readings of four tensiometer stations (a station at each replication with two tensiometers in each, at depths of 30 and 60 cm) and with data from a class A evaporation pan. The wetting front did not exceed 70 cm. At each tensiometer station, two units of moisture suction were installed and pH, EC and Cl were regularly analyzed with field kits. These findings also assisted in adjusting irrigation and fertigation quantities and scheduling. Irrigation water was obtained from a well located near the experimental site. The chemical characteristics of the water are described in Table 3.



Map of China and the experiment site.

Treatments

Eight treatments, each replicated four times were tested, and all irrigated with the same MIS system (Table 4). Treatment one is a control (FYM; 1,700 kg/ha) with fertilizer and FYM applied only in 2004, representing 75, 42 and 7.5 kg/ha of N, P_2O_5 and K_2O, respectively. This was given as a single application at planting time in 2004. In common with all the other treatments only very small maintenance quantities

Table 1. Initial available soil nutrient contents, organic matter content and soil pH on the experimental site, before starting the experiment (analysis taken in April 2004).

Depth	Organic matter	Available N	Available P	Available K	pH
	g/kg	------------------	*mg/kg*	------------------	
0-30cm	8.80	80	7.5	76	7.3
30-60cm	9.72	77	4.0	88	6.5
60-90cm	8.22	79	4.1	99	6.3

Table 2. Analysis of the manure applied to all the treatments (April 2004).

Parameter	Unit	Value
Moisture	%	32.03
Organic matter	g/kg	35
EC (2:1 water)	dS/m	5.41
Total N	%	4.16
Total P_2O_5	%	3.76
Total K_2O	%	2.08

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Table 3. Chemical characteristics of irrigation water (analysis from April 2004).

Parameter	Unit	Value	Parameter	Unit	Value
pH		7.8	Fe	ppm	0.016
EC	dS/m	0.71	Mn	ppm	Trace
NO_3	ppm	3	Cu	ppm	Trace
P	ppm	0.11	Zn	ppm	0.0018
K	ppm	3.8	As	ppm	<0.01
Na	ppm	21	Hg	ppm	<0.0004
Cl	ppm	61	Cd	ppm	0.0024
SO_4	ppm	40.3	Cr	ppm	<0.004
Hardness	ppm	32	Pb	ppm	<0.01
TDS	ppm	489	Hydroxybenzene	ppm	<0.002

Table 4. Treatments and rates of nutrients applied.

Treatments		2004			2005			2006		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
		kg/ha								
1	FYM	75	42	7.5	0	0	0	0	0	0
2	FP	75	42	7.5	180	100	100	130	140	170
3	N1PK1	120	90	45	150	150	120	210	225	270
4	N2PK1	180	90	45	225	150	120	315	225	270
5	N1PK2	120	90	90	150	150	180	210	225	405
6	N2PK2	180	90	90	225	150	180	315	225	405
7	N1PK3	120	90	135	150	150	240	210	225	540
8	N2PK3	180	90	135	225	150	240	315	225	540

of nutrients were applied before the experiment started. Treatment two is farmers' practice (FP), in which fertilizer rate is based on local experience. This also received 1,700 FYM kg/ha in 2004. All other fertilizers were applied as basal fertilizer which was broadcasted after apple harvest or as basal fertilizer and with fertigated N once in the early spring of the following year. Treatments three to eight received a basal dressing and fertigation at rates as described in Table 5. Fertigation rates were made in combination with two levels of N and three levels of K, while P was applied through the fertigation system at the same rate in all treatments (90, 150 and 225 kg P_2O_5/ha in 2004, 2005 and 2006, respectively). The amount of nutrients applied to treatments three to eight in 2005 and 2006 were also based on leaf and soil analysis. Table 4 shows the treatments with the different fertigation rates of N, P and K in the treatments during 2004, 2005 and 2006.

Approximately 20-30 per cent of the N, 70 per cent of the P_2O_5, and 30-40 per cent of the K_2O in treatments three to eight were applied as basal fertilizer in a groove encircling the tree in the early spring in 2004, and in middle October in 2004 and 2005 (Table 5). The remaining amounts were applied during early April to mid-July in the following year in seven-to-eight doses through fertigation.

Composted FYM (poultry litter compost) of 1,700 kg/ha was applied annually as a basal fertilizer to all treatments in the early spring in 2004, and after apple harvest in 2004 and 2005.

Fertilizers applied as a basal dressing and in fertigation (Table 5). were urea and mono-ammonium phosphate (MAP) as the N source, MAP and MKP as the P_2O_5 source, and MKP, MOP and SOP as the K_2O source. During 2004 and 2005, MOP amounted to at least 50 per cent of the K_2O stipulated, the remaining being given as SOP and MOP in each fertigation application. In 2006, SOP was applied as basal dressing (40 per cent of the stipulated amount) and MOP through fertigation. Urea, DAP, SSP and SOP were used for the basal application, while urea, MAP, MKP, SOP and MOP were used in fertigation.

Tree growth

Tree height, trunk circumference, trunk height, number of main branches, length of main branch and main branch circumference were measured at the beginning of the experiment

Table 5. Fertilization scheme.

Year	Nutrient	Basal dressing: Time of application	Basal dressing: Rate of total	Fertigation: Time of application	Fertigation: Rate of total	Fertigation: No. of applications
			%		%	
	N	March	20	Apr.-June	80	3
2004	P_2O_5	March	70	Apr.-Aug.	30	7
	K_2O	March	30	Apr.-Aug.	70	7
	N	Oct. 2004	20	Apr.-June	80	5
2005	P_2O_5	Oct. 2004	70	Apr.-Aug.	30	8
	K_2O	Oct. 2004	30	Apr.-Aug.	70	8
	N	Oct. 2005	30	Apr.-June	70	6
2006	P_2O_5	Oct. 2005	70	Apr.-July	30	8
	K_2O	Oct. 2005	40	Apr.-July	60	8

Note: The table represents fertigation management in treatment three to eight.

Measuring the size of apple fruits at the experiment. Photo by Yan Peng.

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(April 2004) and two years later, at the end (September 2006).

Leaf analysis

Leaves from each treatment were collected in mid-July of 2004, 2005 and 2006. 32 leaf samples, each sample of 100 leaves collected from five trees per treatment were analyzed for N, P and K in the lab in Shandong Agricultural University. After oven drying (60°C for 6-8 hours) the leaves were ground and screened. Samples were then taken for wet digestion (sulfuric acid and hydrogen peroxide) and the digestion solution used for N, P and K estimation. N was determined using the Kjeldahl method of NH_3 distillation followed by titration. P was determined colorimetrically using the vanadomolybdate method, and K by flame photometry.

Soil analysis

Soil samples were taken from the beginning of the experiment before commencing (March 2004) and during October 2004, 2005 and 2006, and were analyzed for available N, P, K, OM, Cl and pH. The samples were taken at three different depths (0-30, 30-60 and 60-90 cm) from each plot in all treatments. The analytical methods used were as follows:

- Available N: alkaline hydrolysisperyasion method
- Available P: Olsen method
- Available K: NH_4Ac extraction and flame photometer
- Soil slowly available K: 2 mol/L cold HNO_3 extraction and flame photometer
- OM: potassium dichromate oxidation method
- Soil Cl: water extraction and silver nitrate titration method
- Soil pH: soil:water = 1:5

Yield and quality measurements

Yield of apples was measured during two picking seasons in 2005 and 2006. Analysis of fruit firmness (kg/cm^2) was measured using a digital fruit firmness tester. Size of apples was determined by passing the apples through holes of a particular measured diameter (see photo).

Results and discussion

Irrigation

During 2005, irrigation was applied at 450 mm, 60 per cent of which was via the fertigation system. In 2006, when only 300 mm was applied, 70 per cent of this was with fertigation. These irrigation levels represent a saving of an average of 160 mm, when compared to conventional irrigation in the region. Daily tensiometer readings allowed optimization of scheduling and quantifying water usage. Water quantity was aimed so that the water front together with precipitation would not exceed 60 cm.

Soil analysis

The soil was analyzed for available N, P and K every year. Slowly available K was analyzed only during March 2004.

Fig. 1 describes the soil available N, P and K concentrations at 0-30, 30-60 and 60-90 cm horizons in October 2006, as compared to the initial level in March 2004. In general, while available N levels decreased during the period 2004-2006, available P and K levels increased in the soil profile.

In October 2006, levels of soil available N in all treatments decreased in all soil profiles, as compared to the initial level of March 2004, and to the much higher levels in the deep layers of 60-90 cm. There was no difference between the various treatments, and soil available N level at all depths in the two controls (FYM and FP) was very similar to that of the other treatments. These observations indicate that N supplied to the trees was not wasteful and did not cause significant leaching of N deeper than the root-zone. This is in accord with the higher levels of available N found at 0-30 cm in all treatments.

The level of available P in the soil was strongly affected by all treatments and increased as compared to the level of March 2004, especially in the 0-30 cm horizon and to a lesser extent, at the 30-60 cm horizon (Fig. 1). There was no significant change in P levels at the 60-90 cm, demonstrating that leaching of P hardly occurred, even when applied through the fertigation system. Interestingly, no difference in soil P levels (0-30 cm) was found between FP and the fertigation treatments. Olsen P above 20 ppm in all treatments (except FYM) indicates sufficient level of P supply. It also shows that P from only FYM (at 1,700 kg/ha/yr) is insufficient as a P supply for an apple orchard.

The level of available K in the soil was strongly affected by K treatment: the more K was applied, the higher the levels of K found in the soil, in all three horizons analyzed. K levels in the K2 and K3 treatments were higher than K1 levels and approximately 30 per cent higher than FP (Fig. 1). Levels of K in horizons 30-60 and 60-90 cm were higher with more K applied in the fertigation system, indicating that under these conditions, K is prone to leaching. At high K fertigation doses (K2 and K3), levels of K at the upper horizon were double the initial levels of 2004, indicating the efficiency of K fertigation.

Leaf analysis

Table 6 shows concentrations of N, P, K and Mg in apple leaves, as an average over three years (2004-2006).

Leaves from the fertigation treatments (three-to-eight) at the N2 application rate were higher in N (Table 6). No significant difference between treatments was observed for P or Mg concentrations. The concentrations of

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these elements in the leaves of all treatments are above the critical deficiency levels, although the values for K appear to be relatively low for apple leaves with reported optimal values in the region of one per cent DM (Ebert, 2009). It has to be taken into account, however, that apple fruit development places a high K demand on the leaves causing a progressive seasonal decrease in leaf K concentration to values which can be as much as 30-50 per cent below the optimal value (Veberič *et al.*, 2005). Besides the fertigation treatments, the time at which the leaves were harvested – in this case mid-July – could have markedly affected the K concentration. Potassium concentration was highest in treatments six and eight (N2PK2 and N2PK3, 0.95 and 0.93 per cent, respectively) while treatment one, with no added mineral N, P and K, presented the lowest K level (0.71 per cent). This can be explained by the fact that the generous FYM application was significant in supplying N, P, and Mg, but not K.

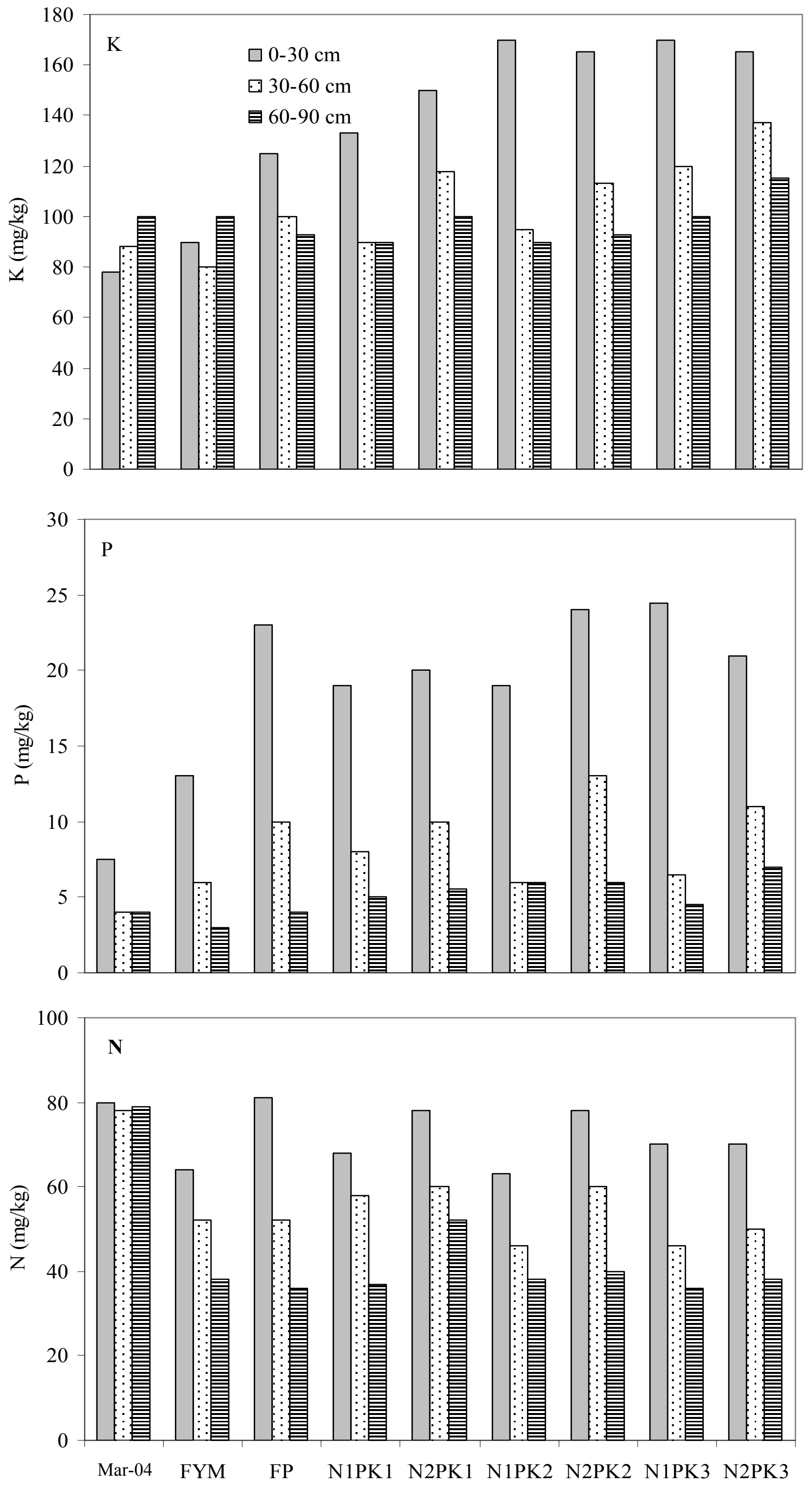

Fig. 1. Levels of soil available N, P and K in the various treatments in March 2004 (left bars) and October 2006.

Table 6. N, P, K and Mg concentrations (% DM) in leaves of apple trees (average of three years, 2004-2006).

Treatment		N	P	K	Mg
		----------	% DM	----------	
1	FYM	2.31	0.16	0.71	0.42
2	FP	2.32	0.15	0.82	0.41
3	N1PK1	2.39	0.15	0.81	0.43
4	N2PK1	2.43	0.15	0.85	0.44
5	N1PK2	2.41	0.16	0.83	0.43
6	N2PK2	2.43	0.16	0.95	0.43
7	N1PK3	2.43	0.17	0.83	0.44
8	N2PK3	2.48	0.16	0.93	0.43

Because the level of available K in the 0-30 cm zone of the soil increased from 2004 to 2006 (Fig. 1), we compared the soil K data to that of the K in leaves, during the same period. Fig. 2 shows the relationship between available soil K in 0-30, 30-60 and 60-90 cm to leaf K. The figure clearly shows that the correlation between this relationship was highest in the upper soil layers: R^2=0.6775 in the 0-30 cm horizon and R^2=0.758 in the 30-60 cm horizon, whereas at 60-90 cm there was no clear correlation. This high correlation between available soil K in the top soil and leaf K concentration provides strong evidence for the benefit of K fertigation which enriches the upper soil horizon in supplying K to the tree.

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Growth of trees

Tree height and trunk circumference were measured at the beginning of the experiment (2004) and 2.5 years later, at the end (2006). The difference (2004-2006) in trunk circumference and tree height is shown in Table 7. No significant differences were found among the treatments; moreover, no correlation was found between these two parameters and apple fruit yield.

Yield

The yield in 2005 (the first commercial yield of the orchard) was low, between 360 to 1,000 kg/ha. While treatment one (FYM) had the lowest yield, the differences between the various treatments with mineral fertilizers and fertigation were not significant (Table 8), except for treatment six (N2PK2), which was significantly higher than other treatments (1,005 kg/ha).

In the following year (2006) a commercial yield was obtained (Table 8). Clearly, the application of only OM (treatment one) is not sufficient to produce reasonable yields, and the addition of fertilizers contributes significantly to yields (treatments two-to-eight). Fertigation treatments (three-to-eight), were in general, better than farmers' practice (treatment two), especially those treatments with high N and K (N2PK3).

In 2005, application of N in treatment two (FP) was higher than N1 in the fertigation treatments, and K levels were similar, which explains the marginal yield response to fertigation in 2005. In 2006, N1 and K levels in the fertigation treatments were much higher than treatment two, which explains the stronger yield effect for fertigation treatments in 2006. The best treatment in 2006 (N2PK3) with a yield of 6,226 kg/ha achieved double the yield of the farmers' practice treatment. When large amounts of N were applied (N2 treatments), K3 was superior to K1 and K2, demonstrating the need for balance in the nutrients applied.

N2 was superior to N1 in both 2005 and 2006 at approximately 10 per cent. Increased K levels in 2006 contributed an additional yield of approximately 33 per cent.

The relationship between N, P and K in leaves and yield in 2006 is shown in Fig. 3. R^2 values for N (0.24) and P (0.02) are much lower than R^2 of K (0.63). This strong relation between K concentration in leaves and the effect of K level in the upper soil profiles (Fig. 2) allows for optimization of the fertilization practices, aiming to reach K concentration of >0.8 in DM of leaves.

Table 7. Change in trunk circumference and tree height between 2004-2006.

Treatment		Change in growth between 2004-2006	
		Trunk circumference	Tree height
		------------------ cm ------------------	
1	FYM	13.5	145.5
2	FP	15.0	151.3
3	N1PK1	12.5	135.1
4	N2PK1	16.1	137.0
5	N1PK2	14.4	152.8
6	N2PK2	15.7	161.8
7	N1PK3	15.5	162.1
8	N2PK3	14.0	160.2

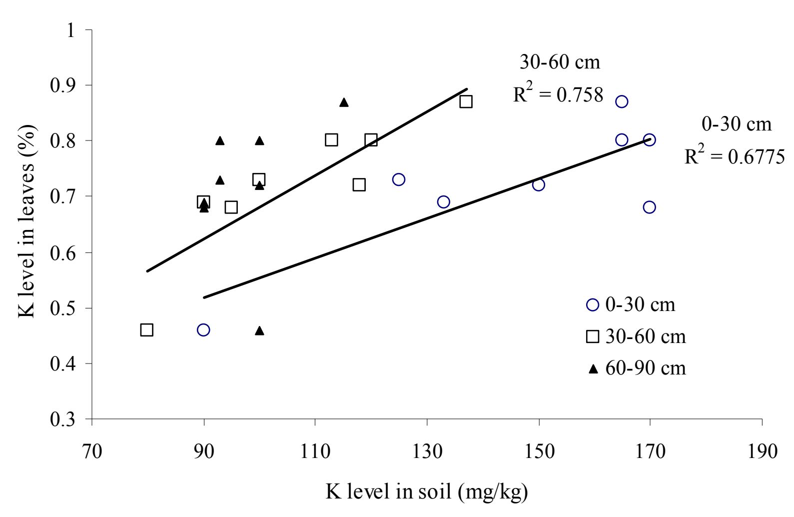

Fig. 2. Correlation between soil K in three horizons (0-30, 30-60 and 60-90 cm) and K in apple tree leaves.

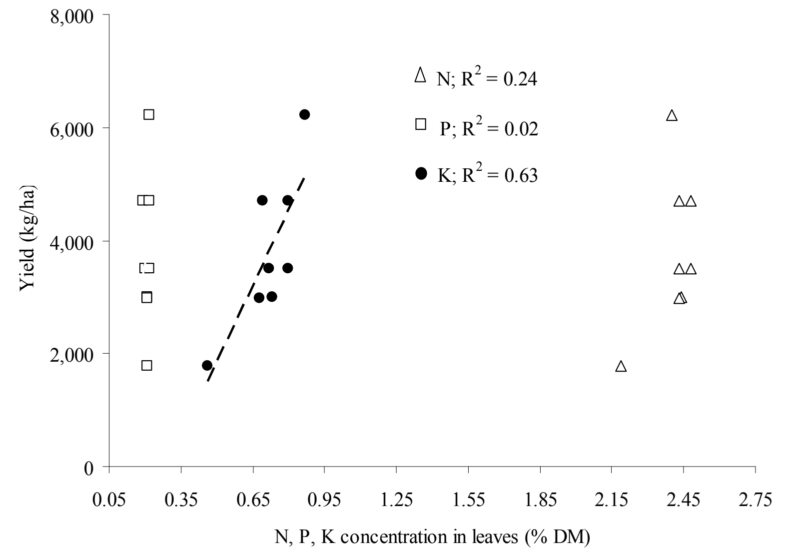

Fig. 3. Correlation between concentration of N, P and K in apple tree leaves and yield (2006).

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Table 8. Apple yields in 2005 and 2006 (kg/ha).

Treatments		2005			2006		
		Yield	0.05	0.01	Yield	0.05	0.01
		kg/ha			*kg/ha*		
1	FYM	361	-	-	1,782	-	-
2	FP	511	-	-	3,004	-	-
3	N1PK1	762	Ab	A	4,705	Ab	AB
4	N2PK1	623	Ab	A	3,501	B	B
5	N1PK2	507	B	A	2,975	b	B
6	N2PK2	1,005	A	A	3,510	b	B
7	N1PK3	617	Ab	A	4,708	ab	AB
8	N2PK3	478	B	A	6,226	a	A
Average treatments							
	N1	629			4,129		
	N2	702			4,412		
	K1	693			4,103		
	K2	757			3,242		
	K3	547			5,467		

Note: All data, except for the data of apple yield in treatments FYM and FP, were analyzed by the statistical mean of two-way ANOVA and LSD. Data in treatments FYM and FP were not tested by two-way ANOVA. Letters for yield represent significance levels at 0.05 and 0.01.

Quality

The physical quality parameters of apples examined in the experiment were size and firmness of fruit. The results presented in Fig. 4 show that the control treatments were rather low in their firmness but similar in fruit weight to the K and N treatments. However, the increased fruit size of the control is mostly attributable to the lower yields achieved. The increased rate of K (from 270 to 540 kg K_2O/ha) improved both fruit firmness and size of fruit. Increase of N improved fruit size, but depressed fruit firmness. It thus appears that the strategy for achieving both large fruit without compromising on firmness is the combination of high N (N2) and high K (K3).

Economic analysis

The results of this experiment confirm that adding more fertilizers and changing the timing of application increases yield and quality of apple. Yet, while higher apple yields and improved quality also increase income, the cost of fertilizers is significant, and an analysis of the net profit is required.

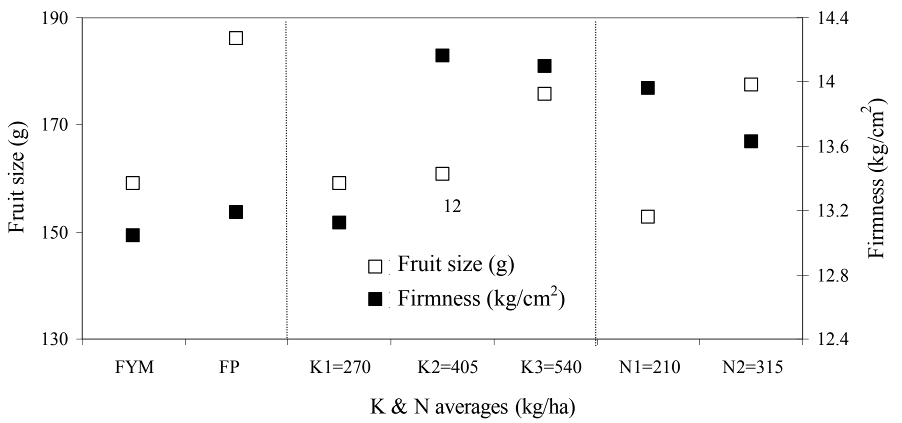

Fig. 4. Average fruit size and firmness (for K1, K2, K3, N1, and N2) of apples (2006).

Total fertilizer application in treatment six (N2PK2) for the three years of the experiment was 914 kg higher (335, 182 and 397 of N, P_2O_5 and K_2O, respectively) than that of treatment two (farmers' practice). The value of this added amount of fertilizers (at market prices of 2007) was 3,172 yuan/ha. At the same time, apple production in treatment six during the two yields of 2005 and 2006 was 1,000 kg greater than that in treatment two. Moreover, apple size in treatment six was larger than in treatment two, which contributed to an additional income. According to the market price at the time, apple prices were 2.5 and 3.5 yuan/kg on average in treatment two and treatment six, respectively, increasing income approximately by 40 per cent as a consequence of the greater size of the fruit.

Our calculation show that the total incomes were 8,787 and 15,802 yuan/ha in treatment two and six, respectively. After debiting the cost of additional fertilizers to treatment six (914 kg, value of 3,172 yuan), the farmer earns a net profit of 3,843 yuan/ha, or 43 per cent higher than the control (farmers` practice). Such a margin is very likely to be accepted by the farmers. Our calculations, however, do not take into account the cost of investment in the fertigation system. Financial incentives to use this system should be made available to farmers by the local agricultural authorities.

Conclusion and recommendations

The application of N, P and K through the combination of a basal treatment and fertigation increased yield and quality of apples, as compared to farmers' practice in the area of the experiment. This increase in yield was not accompanied by faster tree development. Using a fertigation system allowed placing N, P & K at the upper soil horizon layer (0-30 cm) and resulted in a significant saving of water (30-50 per cent). Using appropriate tools to monitor depth of

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wetted zone and level of nutrients in the soil profile is highly recommended.

Taking the yield, quality and leaf nutrient concentration of apple response to the different treatments into account, the appropriate rate of N applied for apple tree fertigation in this area of brown earth soil is 180-460g/tree/yr for three-to-six year-old trees respectively, and the rate should be increased gradually with tree growth over that period. The recommended ratio of N: P_2O_5:K_2O is 1:0.75-1.0:1.5-1.8 on newly-cultivated soil.

Basal fertilization is recommended to be integrated with fertigation: 20-30 per cent of total N rate should be applied as basal fertilizer after harvest, 30 per cent of N through fertigation at early spring and rest in three-to-four fertigation applications before flower-bud differentiation (end of June). For potassium, 20-40 per cent of the total K_2O should be applied as basal dressing in autumn, after harvest, as SOP, and the remainder as MOP in fertigation in six-to-eight applications during spring-summer. The number of MOP applications in fertigation may be reduced, but concentration applied should not exceed 0.4 kg MOP/m^3 (equivalent to 240 ppm). Approximately 70 to 100 per cent of total P_2O_5 can be applied as base fertilizer. If P is fertigated, it should be split equally between spring and summer fertigation.

From samples obtained over the years of the experiment, leaf K concentrations were found to correlate well with available soil K values. During 2006, when commercial yields were obtained, a high correlation was also obtained between leaf K concentration and yield. In mature trees, a K level of >0.8 per cent is recommended for maximum yield, however, the parameter of leaf K for diagnosis of adequacy of nutrition of young trees in the region should be studied in greater detail.

Maximum fruit size and firmness were obtained with high rate of N and K. It is recommended that in orchards where there is a potential for achieving large fruit with high N levels, that appropriate and special care is to be given to K nutrition, in order to supplement the size with firm fruit.

These agronomical recommendations are followed by economic analysis showing that on an average, due to higher yield and quality, best treatments with fertigation (N2PK2) bring an additional 40 per cent in net income for the farmer.

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II Potato – the hidden treasure

A. Krauss[(1)]

"*Potato – the hidden treasure*" is the motto of the International Year of the Potato, as declared by the UN for 2008. The Swiss Post Office even issued a special stamp for the occasion (www.post.ch, 2008).

Good reasons to celebrate this crop

It is number four in the global diet after rice, wheat and maize as a major staple crop

Indigenous to the Peruvian Andes and cultivated there for thousands of years, the potato plant was unknown to the rest of the world until the 16th century. It was first encountered by the Spanish conquistadors in their search for gold in Peru and it was they who returned home with it to Spain. First evidence of potato growing in Europe dates from 1565, in the Canary Islands. In the beginning, potato was considered as an exotic curiosity, but very soon it became an important staple food, particularly in Ireland. Since only a few varieties were initially introduced, however, genetic diversity was rather limited which left the crop very vulnerable to pests and diseases.

In the 17th century sailors took the tubers with them on their journeys and by this means the potato reached India, China and Japan. Irish immigrants imported the potato into North America in the early 1700s.

Dependence on this crop, especially by the poor, was the initial trigger for the Great Irish Famine of 1845 when late blight caused a disastrous crop failure which ultimately resulted in the deaths of about a million people.

Today, the global production is around 320 million mt, 40 per cent of which is produced in Asia, almost the same (38%) in Europe, 12 per cent in North and South America and some four per cent in both Africa and Oceania (FAO, 2008a). This represents a substantial shift over the past 30-40 years in favour of Asia; in 1970 Asia produced only around 35 million mt or less than 12 per cent of the global 298 million mt, but Europe produced some 232 million mt or 78 per cent of total (Fig. 1). Currently, China is the largest single producer (73 million mt in 2005), followed by the Russian Federation (36 million mt), India (25 million mt) Ukraine and the USA (19 million mt each).

International Year of the Potato, Helvetia. A stamp issued by the Swiss Post Office. (http://www.swisspost.ch/en/print/pm-1-2008-jahr-der-kartoffel-085.jpg).

In Asia, potatoes have gained the status of a highly prized cash crop.

Compared to other major root crops potatoes represent about 43 per cent of the global output of root- and tuber-crops, followed by cassava with 30 per cent, and sweet potato with 17 per cent.

It is a very versatile crop suitable for both direct consumption and as an industrial crop

First of all, potato tubers are "non-fattening" because 100 g boiled potato contains only 87 kcal of energy and hardly any fat. For human consumption the potato tubers are not eaten raw but cooked to break down the starch. Potatoes provide the basis of many common dishes in which they are prepared in different ways. Amongst others they are baked, steamed, cut, sliced, mashed, fried, or roasted. Freeze-dried potato flour is added to grain flour for bread baking. In other words, there is a wide range of recipes around the world reflecting the versatility of the potato tuber as a source of nutrition. The highest per capita potato consumption is seen in Europe (93 kg/capita/yr), followed by North America (48 kg) and Oceania (43 kg). Globally, the per capita

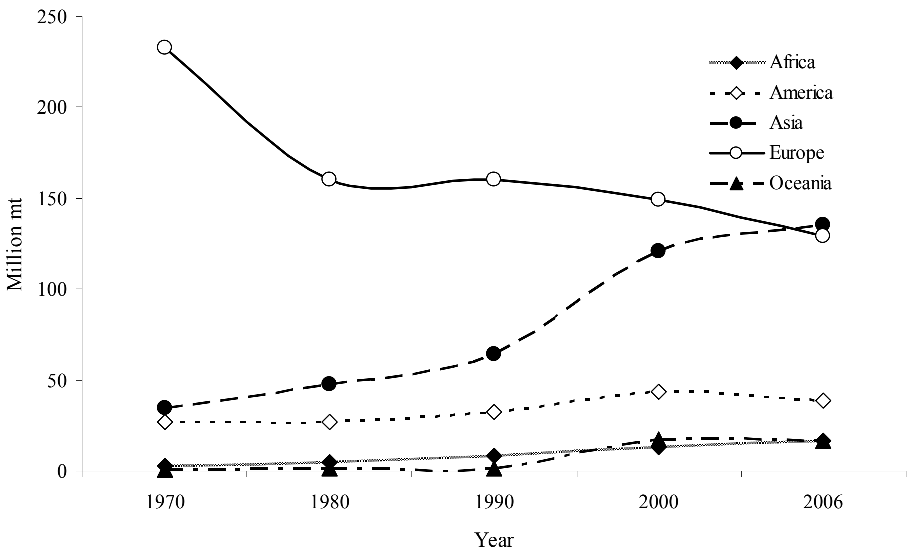

Fig. 1. Potato production by continent (source: FAOSTAT accessed 10-2008).

(1) Dr. Adolf Krauss was the Director of the International Potash Institute (IPI) 1994-2004.

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consumption is 32 kg/yr (figures for 2003, FAO 2008a).

Starch from potato tubers is used in the pharmaceutical, textile, wood and paper industries, in the latter, for example as an adhesive. Since potato starch is 100 per cent biodegradable it is of value as a substitute for polystyrene and other plastics in disposable plates, dishes etc. Some potato is processed into fuel-grade ethanol. In Germany, for example, about 60 per cent of total potato production is used for food, 30 per cent for starch production and about two per cent for ethanol production (figures for 2005/06; Statistical Yearbook 2007).

Its tubers represent a very high nutritive value

FAO (2008b) shows the following nutrient content of potato tubers (per 100 g, after boiling and peeling):

Carbohydrate	20.13 g
Fiber	1.8 g
Fat	0.1 g
Protein	1.87 g
Water	77 g
Potassium	379 mg
Phosphorus	44 mg
Calcium	5 mg
Iron	0.31 mg
Vitamin C	13.0 mg
Niacin	1.44 mg
Thiamin	0.106 mg
Riboflavin	0.02 mg

The carbohydrates provide energy, fiber stimulates intestinal peristalsis, and the quality of tuber protein has the highest biological rating amongst plant products, comparable to that of egg. Of importance are the high contents of potassium and vitamin C, the presence of the latter the reason for potato often being called the "lemon of the North". The high K content is indicative of a particularly high K fertilization requirement; based on the above figure a moderate yield of 30 mt/ha would remove from the field some 110 kg K or the equivalent of 230 kg potash fertilizer i.e. K contained in almost five bags of muriate of potash (MOP).

It can be cultivated in a wide range of climatic and soil conditions

Potatoes are cultivated throughout the world except in the hot tropics and under cold arctic conditions. Under arid conditions drip irrigation is fairly common. Numerous cultivars, differing in tuber color, shape, size, starch content and maturity period provide a wide choice to accommodate the requirements of local soil and climate conditions, market and consumer expectations.

However, potatoes are very sensitive plants, especially with regard to tuber initiation and tuber growth. For instance, long daylight (18 h) or high temperature (30°C) prevents tuber formation. The control mechanism behind this relates to phytohormone activity, in particular in the ratio of the inducing phytohormone abscisic acid to the inhibiting hormone gibberellic acid; this ratio is rather low under non-inducing conditions but high under inducing conditions e.g. short day and/ or moderate temperature (Krauss & Marschner, 1982). It was also observed, that under constant high temperatures that root growth was strongly depressed which might be one of the reasons for disturbed phytohormone production and thus failure to induce tubers.

Another interesting aspect is the fact that tubers subjected to high temperature (30°C) ceased growth and, as important, both the incorporation of ^{14}C-labelled assimilates into starch, and the starch content were significantly reduced. Since the incorporation of ^{14}C-labelled assimilates into the sugar fraction was not affected by high temperature it can be assumed that under this adverse temperature regime the activities of some of the enzymes involved in starch metabolism were depressed (Krauss & Marschner, 1984).

Glassy-end tubers as often observed in hot dry summers are low in starch, which may relate to impaired starch formation. The treatment of growing tubers with gibberellic acid also changed the carbohydrate composition and enzyme activities towards a pattern which is characteristic of terminating the storage process (Mares *et al.*, 1981), similar to that observed at high tuber temperature.

And even small-scale farmers can achieve enough yields

Potato harvest can satisfy small-scale farmer's own food requirements and even contribute to income by selling excess potatoes at market. In Ireland in the 18th century, 0.6 ha of land used for potato cultivation was enough to supply a family of six for a whole year; to feed the same family on cereals would require four to six times more land (Ali 1999). Indeed, when the dry matter yield (assumed 20 per cent of fresh weight) of potato is compared with e.g. wheat it shows that for instance in India 3.28 mt/ha dry matter of potato (20% of 16.4 mt/ha) exceeds 2.6 mt/ha of wheat. Similarly, in the Netherlands, with the highest global potato yields of 44.7 mt/ ha, 8.94 mt/ha potato dry matter compares with 7.1 mt/ha wheat (figures for 2007; FAO 2008a).

However, the question arises as to whether the production of potato is also economical, from the viewpoint of energy use. In this respect Pimentel & Pimentel (2007) have considered the ratio between energy input and output for a range of crops. For potato cultivation, the input/output ratio in industrialized countries is positive, 1.33:1 in the USA and 1.57:1 in the UK, indicating that despite energy-rich inputs such as fertilizers, fuel and transportation, the high yields produced 30-60 per cent more energy than used in production. In the Philippines, however, with relatively low potato yields, the input of energy and labour required is high when compared to yield; the ratio

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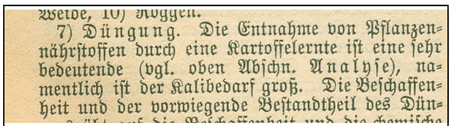
of kcal input/output is 1:0.42. In contrast, production of cassava in some developing countries (Thailand, Colombia, Vietnam and Nigeria) gained almost four times more energy than used in its production.

FAO (2008b) sees a particular function of women in potato production in developing countries. Rural women provide most of the labour – from conservation and seed selection to planting, harvesting, storing and marketing. In Peru for instance, the migration of men into urban centers in search of income has left women farmers responsible for almost 70 per cent of family farm work. From this type of evidence FAO concludes that women in developing countries play a central role in family food security.

A crop with a high yielding potential like the potato needs adequate supply of plant nutrients

In the IPI Bulletin No. 8 on potatoes, Perrenoud (1993) evaluating different sources showed that a good potato crop may remove at harvest around 100 kg/ha N, 50 kg/ha P_2O_5, 200 kg/ha K_2O, and about 10 kg/ha of both CaO and


Weide, 10) Roggen.
7) Düngung. Die Entnahme von Pflanzennährstoffen durch eine Kartoffelernte ist eine sehr bedeutende (vgl. oben Abschn. Analyse), namentlich ist der Kalibedarf groß. Die Beschaffenheit und der vorwiegende Bestandtheil des Dün-

An extract from Thiel's Agricultural Encyclopedia, 1880.

MgO. Total uptake (tubers and haulm) amounts to about 200 kg/ha N and 300 kg/ha K_2O, the maximum uptake being found to occur 95 to 120 days after planting with daily uptake rates of 2.5 kg N and 6.6 kg K/ha/day. Awareness of this high nutrient removal was already appreciated in the 19^{th} century as published in "Thiel´s Agricultural Encyclopedia" (issued and edited around 1880 by Birnbaum & Werner), stating that "the removal of plant nutrients in harvested potatoes is very considerable, namely the demand for potassium is great".

How does the potato plant respond to different nutrients? Let's have a look at more pronounced effects:

Nitrogen

Nitrogen (N) is a constituent of amino acids thereby playing numerous roles in growth and yield formation of plants. It is therefore not surprising that potato plants also respond well to N fertilization. However, as shown by Milford & Johnston (2007), it is essential to balance N supply with potassium (K) in particular (Fig. 2) because as reviewed by Pettigrew (2008), K is directly or indirectly involved in plant protein metabolism, beginning with the stimulation of NO_3 uptake and transport within the plant. Consequently, N fertilized together with adequate K results in better N recovery, in the given example, at the highest N rate from 35 per cent with NP to 54 per cent with the NPK treatment. This higher recovery also substantially reduces N loss to the environment. In this context it should be mentioned that potato plants have a rather flat root system. Therefore, high rates of N application at the beginning of vegetation present the risk of excessive N supply as a consequence of the high mobility of nitrate which allows it to be leached below the root zone with subsequent contamination of the groundwater. There is therefore a need to judiciously synchronize N supply with N demand of the crop. Perrenoud (1993) analyzed a range of fertilizer recommendations worldwide and concluded that a crop with less than 20 mt/ha yield is fertilized on average with 112 kg/ha N whereas at a yield above 25 mt/ha the crop receives 131 kg/ha N.

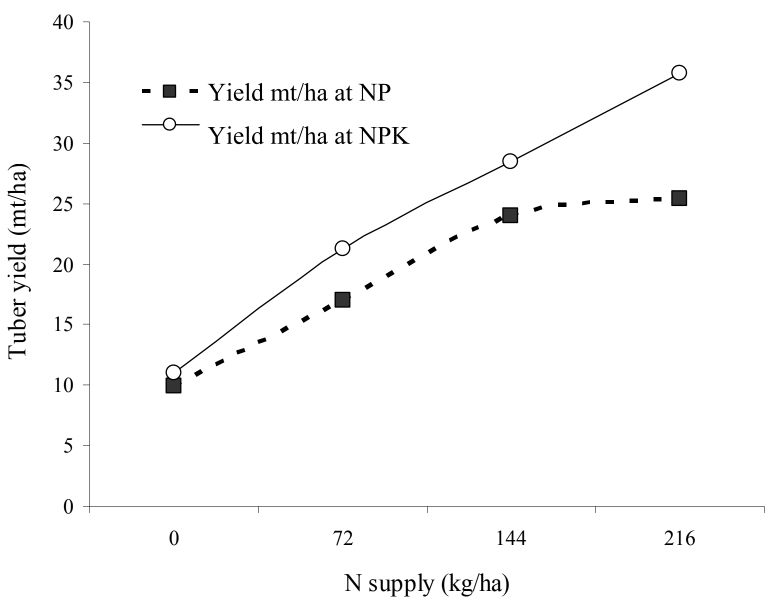


Fig. 2. NK interaction in potato (source: Milford & Johnston, 2007).

N deficiency is indicated by yellowish chlorotic leaves, starting in physiologically older parts of the plants. In contrast, plants supplied with excessive N show abundant shoot growth with dark green leaves.

Excessive N rates also affect the control mechanisms of tuber initiation and tuber growth. As shown by Krauss & Marschner (1982), continuous N supply resulted in prolonged stolon growth and prevented the formation of tubers because under these adverse conditions the activities of gibberellic acid (inhibitor) was relatively high compared to that of abscisic acid (promoter), i.e.

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continuous N initiated hormonal events similar to those under non-inducing long day conditions. Only after discontinuing the N supply for a few days did tuber initiation begin because of the shift favoring the activity of the promoting phytohormones. Resupplying N reversed the effect resulting in a cessation of tuber growth and the formation of new stolons at the apex of the tuber. By alternating supply and omission of N, tubers could be formed resembling a string of pearls (Plate 1).

Phosphorus

As summarized by PPI-PPIC in Better Crops (1999), phosphorus (P) is vital to plant growth and is found in every living plant cell. It is involved in several key plant functions, including energy transfer, photosynthesis, transformation of sugars and starches, nutrient movement within the plant and transfer of genetic characteristics from one generation to the next.

As already mentioned, a moderate crop removes some 50 kg/ha P_2O_5 as harvested tubers. On average, potatoes are fertilized at lower yield level with 87 kg/ha and at higher level with 116 kg/ha P_2O_5. Sites with calcareous soils or acidic soils with high concentrations of free aluminum need special care because of P fixation in such soils.

Lack of supply in P is indicated by stunted growth with small, dark-green to purple discoloured leaves.

Potassium

As indicated, potassium (K) can be considered as a synergist in N metabolism. Quite apart from that, however, K is an important factor in many physiological processes such as osmoregulation, cell expansion, stomatal movement, and sugar metabolism. In this context, the proceedings of a recent conference on "Potassium and Magnesium, advances in research and application", should be mentioned. This was organized by IPI, IFS and the Sabanci University and held on 7 December 2007 in Cambridge, UK, and includes several papers reviewing the role of K (and Mg) on yield and quality formation in plants. The papers were later published at the Physiologia Plantarum, v. 133 (4). (see also at "New publications", page 19.)

Plate 1. *Resupply of nitrogen promotes formation of new stolons. Photo by A. Krauss.*

Returning to the NK partnership, K uptake even exceeds the uptake of N. As mentioned by Perrenoud (1993), potatoes have a total uptake of around 300 kg/ha K_2O, of which 2/3^{rds} or 200 kg/ha are removed from the field with the harvested tubers. However, unlike N the K concentration in soil solution is rather small; movement of K towards the roots is mostly by diffusion - and not by mass flow as for nitrate - following a concentration gradient created by the removal of K from the soil solution adjacent to the root surface through uptake. As reviewed by Britto & Kronzucker (2008), K uptake by plant roots is an energy demanding active process requiring ATP.

In soils, K is compartmented in four distinct pools differing in availability to plants: (i) soil solution, (ii) exchangeable K, (iii) non-exchangeable K, and (iv) structural K (Krauss & Johnston, 2002; Rengel & Damon, 2008). There are reversible dynamic exchange processes between the pools. Potassium taken up from pool (i) is replenished by K from pool (ii) and – to a lesser extend – from pool (iii); after fertilization with potash, excessive K in soil solution, i.e. pool (i) is reabsorbed by the exchange sites of the clay minerals and organic substances. The bulk of K in plants derives from pool (i), the soil solution and thus from the easily available pool (ii), the exchangeable K. K from pool (iii), the non-exchangeable K is less available to plants albeit Trehan *et al.* 2005 (quoted by Rengel & Damon, 2008) identified several potato genotypes which could utilize K from the non-exchangeable pool. The genotypic difference in utilization of non-exchangeable K seems to be based on exudation of K-mobilizing compounds. Another interesting aspect in this context is the fact that potato grown in flowing nutrient solution culture required 9 times higher external K concentration than wheat or sugar beet to achieve 90 per cent of maximum yield (Trehan & Claassen, 1998).

Although K efficient potato genotypes may utilize non-exchangeable K and thus cope better under K deficient conditions, the replacement of K removed by the crop by adequate fertilization is indispensable for the benefit of the following crop. The high total K uptake within a short time span on one hand and the obvious need for relatively high K concentrations in soil solution on the other, are important indicators of the need to ensure adequate K supply, i.e. plenty of easily available K for potatoes.

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K deficiency is shown by necrotic leaf edges, starting on older leaves (Plate 2), often accompanied by early wilting. Excessive K supply on the other hand can adversely affect uptake of other cations, Mg in particular.

Another interesting aspect is the function of K in pest and disease resistance in plants. Nutrition of plants in general has a substantial impact on the predisposition of plants to be attacked or affected by pests and diseases. By its influence on growth pattern, anatomy and morphology and particularly chemical composition, the nutrition of plants may contribute either to increase or decrease resistance and/or tolerance to pests and diseases. As evident from the compilation of Perrenoud (1990) it has been found that K-deficient plants, especially in conjunction with high N rates contain relatively high concentrations of low molecular weight metabolites such as sugars and amino acids. The associated soft tissues (pale in colour) provide a good feeding ground for pathogens, as well as attracting aphids and allowing their easy access. Amtmann *et al.* (2008) develop further the relationship between K nutrition and disease resistance by looking into early defense signaling and the hormonal pathways in defense. Datnoff *et al.* (2007) show in their compilation that bacterial diseases of potatoes respond differently to K: incidence of potato scab (*Streptomcyes scabies*) is increased but that of soft rot (*Erwinia carotovora*) decreased. Canker (*Rhizoctonia solani*) can be either increased or decreased. Potassium depresses the incidence of late blight (*Phytophthora infestans*) as evident for example from the IPI-PRII-CPRI experiment in Jalandhar, Punjab (1997). Plots with no K added (-K) suffered severely from *Phytophtora infestans* (Plate 3).

Plate 2. *Typical symptoms of K deficiency in potato leaves. Courtesy of K+S KALI.*

Appearance of mosaic virus is lowered by K, whilst the incidence of leaf roll virus can be both increased and decreased. In other words, there is still space left for further research into the relationship between nutrition in general and K in particular and the incidences of pests and diseases in potatoes and other crops. The economic damage that pests and diseases can bring about should not be underestimated: Oerke *et al.* (1995) report that, during 1988-1990, of the total attainable production of 8 major crops (wheat, corn, rice, barley, soybean, cotton, potato and coffee), worth US$580 billion, about 42 per cent or US$240 billion are lost due to insects (15%), followed by pathogens (13%) and weeds (13%).

Plate 3. *Late blight (Phytophthora infestans) did not affect the plots with K, but devastated the crop without K treatment. Photo by P. Imas.*

K nutrition and potato quality is another aspect of economic relevance. In an overview on the K effect on yield quality, Krauss (2005) concluded "…crop quality is not a singular item that can easily be measured, it is rather complex and refers to subjective and objective parameters such as nutritive value, processing properties, taste and appearance. Although components of crop quality are genetically controlled, the nutrition of plants can alter the expression to a substantial extent. Through its versatile function in plants, K in the concept of balanced fertilization plays a particular role in quality formation as shown in numerous experiments and field trials around the world. Complying with the quality standards set by consumers and environmentalists warrants farmers who apply balanced fertilization to remain competitive in the market because of an ecologically sound and economically viable production method…". As far as potatoes are concerned, Haeder (1975) showed, for instance, that in potato plants receiving adequate amounts of K, 80 per cent of foliar applied ^{14}C was translocated within 2 h into the tubers, whereas K deficient plants retained more than 50 per cent of the absorbed ^{14}C in the shoot. A higher assimilate storage adds to nutritive value and quality. Potato trials in Bulgaria revealed that the content of reducing sugar dropped from 0.56 per cent with NP to 0.04 per cent

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with balanced fertilization with K and Mg together with NP (Nikolova, 1999). A low concentration of reducing sugar in potato tubers is mandatory for tasty and bright coloured potato chips and crisps. Gerendás *et al.* (2007) showed that increasing K always raised the citrate contents, but lessened the contents of reducing sugars, which serve as a precursor for acrylamide formation. Highest acrylamide contents (considered "likely carcinogenic for humans") were observed in tubers grown with high N and inadequate K supply. These results demonstrate that nutrient supply has a significant impact on the contents of acrylamide precursors and thus for acrylamide formation during frying.

Field trials with potatoes in Germany showed that the incidence of black spot decreased with increasing K content of tubers. Improving the K supply also led to increased starch content of potato tubers, the beneficial effect being more pronounced with sulfate of potash than with potassium chloride. The higher starch content returned a higher sales price with a quality bonus (Orlovius, 1996). Bansal & S. Umar (1998) reported from field trials in India that supplying potato with adequate potash increased tuber yield and dry matter content. At the same time, for potatoes grown for processing, chip color was improved and storage loss of fresh tubers was reduced. The latter is of particular economic importance because the market price of potatoes for instance in India increases considerably for some weeks after harvest. As an example, during the season 1997-1998, the price increased from Rs./kg 4.5 at harvest to Rs./kg 6 two weeks later and Rs./kg 8 four weeks later. This increased the value-cost-ratio (VCR) of potash from 16.6 at harvest to 21.4 and 28.5 two and four weeks later, respectively.

Potassium plays a particular role under saline conditions. As summarized by Shabala & Cuin (2008), salinity affects plant growth by imposing ionic and osmotic stresses because high Na levels in soil solution drives water out of cells. Secondly, there can be a specific Na toxicity, and third, salinity-induced nutritional disorders can occur in particular, induced K deficiency as a consequence of leakage of K from the root cells. In relation to the latter, high Na concentration in soil solution also reduces the activity of other essential nutrients, including K, and in addition, Na competes with K for uptake sites. On the other hand, salt-tolerance, as discussed by Shabala & Cuin (2008) "… is a complex multigenic trait …and is also multifaceted physiologically, with numerous tissue- and age-specific components involved…". Interestingly in this context, as shown by Krauss (unpublished results), ^{22}Na applied to leaflets of rooted potato sprouts is immediately translocated to the roots and excreted into the nutrient solution. This observation is in accord with other reports that potato is relatively sensitive to salinity and that K cannot to any great extent be substituted by Na (Marschner, 1995). The high K demand of the crop thus calls for particular care under saline conditions (amelioration, adequate K supply).

Magnesium

Magnesium (Mg) is often called *the forgotten nutrient*. Uptake and removal of Mg from the soil by potatoes is rather low (10 kg/ha MgO) as compared to K (up to 200 kg/ha K_2O). In the past this relatively low demand has not placed any major constraint on yield formation. However, continuously increasing Mg removal by higher yielding varieties and the tendency to focus on highly concentrated straight fertilizers will sooner or later give rise to the need for Mg fertilization on light soils. Calcareous soils, acidic soils with high concentrations of free Al as well as high rates of application of K and/or NH_4 fertilizers on Mg poor soils, especially sandy soils, all respond to Mg fertilization because of competition in Mg uptake. No doubt, Mg is one of the indispensable plant nutrients. As summarized by Cakmak & Kirkby (2008), Mg exerts a major influence on the partitioning of dry matter and carbohydrates between shoot and roots. Accumulation of carbohydrates in leaves is typical of Mg deficiency because Mg plays a fundamental role in phloem loading of sucrose. With impairment of phloem transport from the leaves it can be imagined that with Mg deficiency in potato not only root growth but also tuber growth suffers. Mg deficiency becomes very visible by developing chlorosis and necrosis on the leaves, especially when plants are exposed to high light intensity (Plate 4). The reason for this effect of Mg deficiency is the generation of highly reactive and detrimental O_2 species due to an over-reduction in photosynthetic e-transport (Cakmak & Kirkby, 2008). These authors plea for a high Mg nutritional status of plants, especially in regions with high light intensity. Foliar sprays

Plate 4. *Mg deficiency in potato leaves. Courtesy of K+S KALI.*

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with Epsom salt can quickly overcome inhibited assimilate transport and the appearance of photo-oxidative damage.

Calcium

Calcium (Ca) uptake and removal by potato crops is in the same order of magnitude as Mg, namely around 10 kg/ha CaO. Apart from the need of Ca for ameliorating saline or acidic soils and thus improving the availability of essential nutrients such as K or Mg, Ca plays a particular role in development of stolons and tubers. Stolons are subsoil growing shoots. The developing tuber induces a high phloem influx but Ca is known to be rather phloem immobile so that there is hardly any Ca translocation from the shoot into the growing stolons or tubers (Krauss & Marschner, 1973). On the other hand, the stolons and developing tubers have the ability to absorb Ca directly from soil solution to meet their demand (Krauss & Marschner, 1975). Due to the relative immobility within the plant, Ca deficiency symptoms start at the growing point in plants. Die back of the apical buds is typical of Ca deficiency because Ca is an integral part of cell walls.

Sulfur

In the past there was no need for fertilization with sulfur (S) in industrialized countries because of the input of atmospheric S to the soil. In the seventies this amounted to up to 100 kg S/ha supplying enough to meet crop demand. However, a number of factors have contributed to reducing indirect S supply to crops. These include rigorous emission control of industry and traffic, the predominant use of highly concentrated mineral fertilizers. Additionally crop demand for S has risen as a consequence of increasing yields. The risk of S deficiency has thus become greater as the result of a lower S input but higher S export by crops. As reported by Schnug (2004), application of up to 50 kg/ha S in Poland to potatoes not only increased yield but substantially reduced the infestation of potato plants with canker (*Rhizoctonia solani*) and potato scab (*Streptomyces scabies*). The fungicidal effect of S relates to the synthesis of S containing metabolites such as phytoalexins, glutathione, glucosinolates and/or the liberation of gaseous H_2S (Bloem *et al.*, 2007). This "sulfur-induced-resistance (SIR)" has the advantage that according to Schnug (2004), the pathogens are unable to develop any resistance to sulfur.

Sulfur deficiency can easily be confused with N deficiency, namely small yellowish pale plants. Apart from leaf analysis, distance from industry, fertilizer practice and soil type may all provide evidence as to whether the plants are suffering from a lack of N or S. Additionally S deficiency always occurs first in the younger leaves whereas N deficiency appears in the older leaves.

A source of dispute is often the question whether potash to potatoes should be given as sulfate (SOP) or muriate (MOP). Pot experiments at the former K+S Büntehof Research Station in Hannover, Germany showed that potatoes fertilized with SOP were earlier in tuber initiation and growth than those fertilized with MOP. This difference in response could have some advantages in regions with multiple cropping when the time frame for potatoes is rather narrow. Also the processing quality (related to starch content) seems to respond better to SOP than to MOP.

Micro-nutrients

Dependent on soil conditions (pH value) there can be a particular requirement for fertilization with micro-nutrients, especially on calcareous soils. Sandy soils can also be poor in micro-nutrients. Foliar application is a common practice, either as chelates or in sulfatic form, sometimes added on application with a macro-nutrient like Mg in Epsom salt. Manganese and copper also exert fungicidal properties, incidences of potato scab obviously being more pronounced with Mn deficiency, and Mn- and/or Cu-containing fungicides are used to control late blight.

In Conclusion

The hidden treasure – the potato – is indeed a worthwhile crop for cultivation albeit the plant itself is sometimes very difficult to handle. The herbaceous habit of growth is inviting for many kinds of pathogens. The bulkiness of the crop places a greater demand on transport both at planting and harvesting as compared to cereals. Moreover the tubers, because of their high water content, require special care during storage. Nevertheless, the high nutritive value and versatility in use of the potato makes it an invaluable crop quite apart from the pleasure of enjoyment of the delightful fragrance of a field of potatoes in blossom.

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Research findings

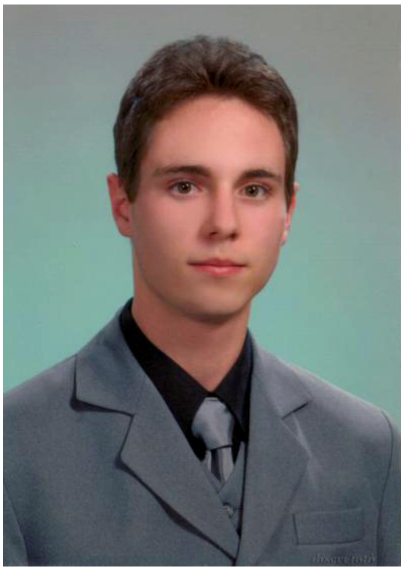
III IPI Award for scientific work on plant nutrition in Hungary

I. Terbe[(1)]

It has become the tradition for the International Potash Institute (IPI) to invite applications every three to four years from interested students at agricultural research facilities and universities in Hungary for an award for the best diploma thesis covering "Potassium in soils and plants". In 2008, the prize was awarded for the fourth time during the "Farmer-Expo" at the agricultural university of Debrecen. Dr. Thomas Popp, IPI Coordinator for Central Europe, was a member of the evaluation panel and presented the prizes to the winners, as well as handing out book prizes to the runners-up. As is the practice in other European countries, Hungarian students studying agriculture must produce a scientific thesis at the end of their studies (BSc and MSc). The topic is of their choice, but must be approved by the institution. The theses are usually based on experimental research or technologies, and are often part of larger research projects lead by the research institute. Usually 10-12 theses are submitted and a five-member panel, consisting of internationally-renowned agrochemists, professors and experts, evaluates the submissions. The theses topics are varied, ranging from the importance of potassium as a plant nutrient, its behaviour in the soil to its manifold physiological effects in plants. As well as focusing on important agricultural crops, i.e. maize, potato and others, many horticultural crops such as grapes, peppers, radish, apple and gooseberry are also included. In addition to results on yield studies, some theses focus on important problems and potential solutions in tree nurseries and ornamental plant production. Besides traditional growing techniques, more and more theses are dealing with advanced growing methods such as "container" and hydro-culture.

(1) *Prof. Dr. István Terbe, Director, Institute of Vegetable and Mushroom Growing, Corvinus University of Budapest, and IPI Program Leader in Hungary.*

In 2008 Norbert Lukács' work "The relationship of the potassium supply and the vegetative production of monthly radish growing" (Pannon University, Georgikon Faculty of Agriculture, Keszthely, under the supervision of Prof. Dr. habil. Katalin Sárdi) was chosen by the jury as the best thesis. The effect of potassium on radish yield at different levels of nitrogen and phosphate was investigated in this work. The amount and ratio of the nutrients contained in the foliage and radish crop was investigated along with the NPK requirements. The most suitable nutrient content of the soil for high quality and quantity of yield were also shown.



Norbert Lukács, award winner for the best thesis.

Second place was awarded to Attila Szabolcsi (University of Debrecen, Centre of Agricultural Sciences, Faculty of Agriculture, supervised by Dr. habil. Imre Vágó and Dr. Csaba Varga, University Lecturer) for his thesis "The role of the potassium in the growing of gooseberry". The data evaluated in this work was part of a larger research project at the University of Debrecen investigating the nutrient and fertiliser requirements of gooseberries, which was commissioned by IPI. In addition to studying the relationship between potassium supply, yield, and yield quality, the effect of chloride und sulphate were also studied. Pectin content was included in the investigation since it is an important parameter during processing of gooseberries. Pectin is used to improve the texture of many products in the food industry.

Attila Szabolcsi, recipient of the award for second place.

Third place was awarded to Márta Heller Szabóné Molnár (University of Debrecen, Centre of Agricultural Sciences, Faculty of Agriculture, under the supervision of Dr. Tamás Monostor, University Lecturer and Dr. József Kruppa, Scientific Assistant), for her thesis "New possibilities for foliar fertilization in potato". The work investigated the effect of potassium on yield increase and quality improvement in the early production of potato in farm trials. The student was looking for a correlation between the availability of potassium and quality parameters, such as starch content and vitamin C content, as well as an interaction with micro-nutrients. Based on the trial, the student

Research findings

was able to make recommendations for the timing of application, and amount of potassium fertiliser.

Márta Heller Szabóné Molnár, recipient of the award for third place.

Several other theses that did not win a prize are worth mentioning as the results of the studies are impressive and important for agriculture and horticulture:

- *Rita László (*Pannon University, Georgikon Faculty of Agriculture, Keszthely, Supervisor: Dr. habil. Katalin Sárdi, University Lecturer): "Examination of annual ornamental plants nitrogen and potassium utilization".
- *Péter Sziráczki (*University of Debrecen, Centre of Agricultural Sciences, Faculty of Agriculture, Supervisor: Dr. József Kruppa, Scientific Assistant): "The effect of K- and Mg fertilization in landscape potato crops".
- *Ilona Kellermann* (University of Debrecen, Centre of Agricultural Sciences, Faculty of Agriculture, Supervisor: Dr. József Kruppa, Scientific Assistant): "The biological bases and opportunities of development of open field early potato".
- *Bernát Poós* (Budapest Corvinus University, Faculty of Horticultural Science, Supervisor: Dr. habil. Károly Hrotkó, University Lecturer): "Evaluation of the effects of different cherry rootstocks in nutrient uptake and utilization" (IPI sponsors this research project).
- *Zoltán Kocsis* (Pannon University, Georgikon Faculty of Agriculture, Supervisor: Dr. habil. Katalin Sárdi, University Lecturer): "The potassium supply effect in the nutrient uptake of malting barley on clayed brown forest soil".

Based on the number of entries and their results, it can be seen that more and more scientific research considers potassium as a major nutrient affecting yield quality and quantity. The young scientists who submit their theses gain publicity through IPI and its work including ongoing trials, and scientific and applied research publications. The published results are also made available in the country so they can be readily incorporated in to agricultural and horticultural practices. As a result of increased interest and the excellent quality of submissions, IPI will accept the next round of submissions by BSc and MSc students in 2010. More details will be made available during 2009. ■

IPI publications in Hungarian

IPI encourages the publishing in a variety of languages. Currently we have publications in 22 languages, among them Hungarian. The following publications in Hungarian are available on our website. For more details, please contact IPI Coordinator Central Europe, Dr. Thomas Popp, thomas.popp@kali-gmbh.com.

Balanced Plant Nutrition in Viticulture for High Yield and Quality. 2006. ISBN 9638512679. Proceedings of the symposium in Keckemét, Hungary, 6-7 September, 2005.

To order a copy, go to http://www.ipipotash.org/publications/detail.php?i=207.

Yield and quality of sugar beet as affected by use of potash.

To download the leaflet, go to http://www.ipipotash.org/publications/detail.php?i=152.

Fertilization of fruit trees.

To order a copy, go to http://www.ipipotash.org/publications/detail.php?i=127

A kálium jelentősége a fűszerpaprika tápanyagellátásában (The importance of potassium for nutrient supply of spice pepper; 2006).

To download the leaflet, go to http://www.ipipotash.org/publications/detail.php?i=208

A kálium jelentősége a vöröshagyma tápanyagellátásában (The importance of potassium for nutrient supply of onion; 2007). By A. Barnóczki and Z. Némethy.

To download the leaflet, go to http://www.ipipotash.org/publications/detail.php?i=235

Potash for yield and quality. IPI Research Topics No. 15. 2006. By Jakab Loch, István Terbe, and Imre Vágó.

To download the leaflet, go to http://www.ipipotash.org/publications/detail.php?i=31

IPI events

July 2009

IPI-Corvinus University Budapest international symposium on "Nutrient management and nutrient demand of energy plants", 6-9 July 2009, Budapest, Hungary.

The symposium will be jointly organized by IPI and Corvinus University Budapest. The venue of the event is Mercure Hotel, Budapest, Hungary. Topics will include quality requirements of crops for biofuels, new and traditional crops for biofuels, energy and CO_2 balance of crops grown for biofuels, and optimal crop rotation and nutrient balance for biofuel plants. The post-symposium tour will be to a biofuels plant and farmers growing energy crops. Registration fee will cover participation at all oral and poster presentations, welcome reception, lunch, morning and afternoon coffee break during the two symposium days, and symposium dinner. The post-symposium tour will be charged separately. For more details see IPI website or contact IPI Coordinator Dr. T. Popp. ■

November 2009

IPI-OUAT-IPNI international symposium on "Potassium role and benefits in improving nutrient management for food production, quality and reduced environmental damages", 5-7 November 2009, Orissa University of Agriculture and Technology (OUAT), Bhubaneswar, India.

The symposium will be organized by the International Potash Institute (IPI), International Plant Nutrition Institute (IPNI), and the Orissa University of Agriculture & Technology (OUAT). It is co-sponsored by the Indian Council of Agricultural Research (ICAR), Fertilizer Association of India (FAI), Bangladesh Fertilizer Association (BFA) and the Pakistan Agricultural Research Council (PARC). The scientific committee, chaired by Dr. J.S. Samra, has selected the following sessions: 1) Nutrient management to meet challenges of food security; 2) Potassium and nutrient use efficiency; 3) Role of potassium and mineral nutrition in alleviation of stress; 4) The effect of quality and nutritional value of agricultural products on human health: the role of potassium; 5) Spatial variability of soil properties and Site Specific Nutrient Management (SSNM); 6) The role of extension in increasing agricultural productivity; 7) Potassium and the environment; and 8) Nutrient mining and input-output balances.

More details will appear regularly on IPI and IPNI websites. ■

New Publications

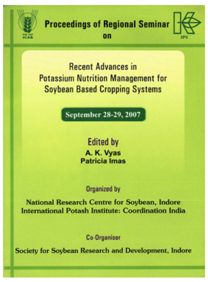
中国玉米钾肥使用手册

Handbook for K fertilizer use on maize in China. 13p., 2008 (in Chinese). By China Agriculture University (CAU) and International Potash Institute (IPI). Authors: Fusuo Zhang, Xinping Chen, Linlin Chen, and Weifeng Zhang (Department of Plant Nutrition, China Agricultural University); Junfang Niu (Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences); Lihua Jiang, Zhaohui Liu, and Haitao Lin (Soil and Fertilizer Institute, Shandong Academy of Agricultural Sciences); Kai Xiao (College of Agronomy, Hebei Agricultural University); Jiagui Xie (Research Center of Agricultural Environment and Resources, Jilin Academy of Agricultural Sciences).

This 13 page handbook presents the development of maize production, the role of potassium on maize, and methods of K fertilizer use in China. The authors collected and analyzed many experimental results in order to demonstrate the function of K in improving maize production and to provide improved recommendations for K fertilizer use on maize in China. This handbook will help technicians and farmers to give and use proper recommendations for K fertilizer use to improve maize yields in China.

Copies are available from Dr. Weifeng Zhang (wfzhang@cau.edu.cn), Department of Plant Nutrition, China Agriculture University (CAU), Beijing, 100193, China.

Download the booklet at http://www.ipipotash.org/publications/detail.php?i=262 ■



Recent advances in potassium nutrition management for soybean based cropping systems. Proceedings of a regional seminar, 28-29 September 2007. National research center for soybean, (ICAR) Indore, India. pp 126. Edited by A.K. Vyas, and P. Imas. Jointly organized by the National Research Centre for Soybean (ICAR), Indore and the International Potash Institute (IPI) Coordination India, in association with the Society for Soybean Research and Development, Indore. The proceedings are published by the National Research Center for Soybean (Indian Council of Agricultural Research; ICAR), Madhya Pradesh.

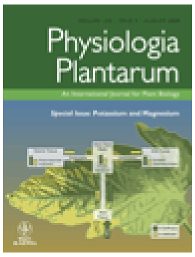
These proceedings include 11 papers describing the role of potassium in soybean yield and post harvest processing quality, the typical soybean production and cropping systems in

New publications

Madhya Pradesh and other states in India, and the typical soils and potassium dynamics in soybean – wheat cropping systems.

To order a copy, contact Dr. A.K. Vyas, Principal Scientist (Agronomy), National Research Centre for Soybean, Khandwa Road, Indore-452017, Madhya Pradesh, India. Tel.: +91 0731 2364879; Email: director@nrcsoya.com.

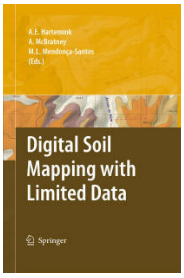
A full copy of the proceedings can be download at http://www.ipipotash.org/publications/detail.php?i=264 ■



Special issue: Potassium and Magnesium. Physiologia Plantarum, V 133, 4, August 2008.

The journal published a special issue with eight selected papers that were presented at the IPI conference together with the International Fertiliser Society (IFS) and the Sabanci University organized in Cambridge, 5-7 December 2007. In the editorial, Dr. I. Cakmak and J.K. Schjoerring write "...there is surprisingly little research and published results on the importance of K and Mg for crop productivity and nutritional quality. Application of these mineral nutrients in crop production is very low in the developing world with high demand for food." The conference held in Cambridge in 2007 aimed to review and elaborate current knowledge and advances in research on K and Mg nutrition in plants, livestock and human beings.

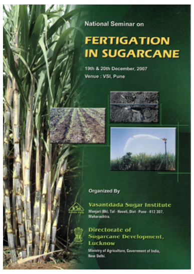
The journal or selected papers can be purchased through http://www3.interscience.wiley.com/journal/120750881/issue ■



Mapping potassium availability from limited soil profile data in Brazil. Prado, R.B., V.M. Benites, P.L.O.A. Machado, J.C. Polidoro, R.O. Dart, and A. Naumov. *In:* Digital Soil Mapping with Limited Data (Eds. A.E. Hartemink, A. McBratney and M. de Lourdes Mendonça-Santos). Published by Springer, ISBN: 978-1-4020-8591-8 e-ISBN: 978-1-4020-8592-5.

Available on http://www.globalsoilmap.net/Riobook.html

The paper by Prado *et al.* is based on a joint research project by IPI and Embrapa Soils, Rio de Janeiro, Brazil. ■



Fertigation in Sugarcane. Proceedings of the National Seminar, 19-20 December 2007, Pune, India. The seminar was jointly organized by the Vasantdada Sugar Institute (VSI) and the Directorate of Sugarcane Development, Lucknow, MOA, India. The proceedings contain 21 papers from various parts of India, and from IPI.

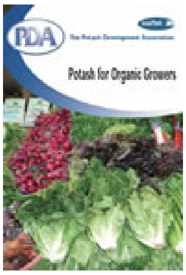
For copies contact Dr. Arun S. Deshmukh, Senior Scientist (Irrigation Water Management) & Manager, VSI. Address: Manjari (Bk), Tal-Haveli, Dist-Pune, 412 307, Maharashtra, India. ■

Publications by the PDA

New publications from the Potash Development Association, UK.

See also http://www.pda.org.uk/

Note: Hardcopies of PDA's publications are available only in the UK and Ireland.



Potash for organic growers. No. 23, update.

This leaflet explains the principles of manuring for organic and conventional systems and the regulations affecting the use of different potash products. http://www.pda.org.uk/leaflets.html#23 ■

in the literature

Perspectives for plant production in Switzerland in 2050. Gaume, A., R. Kölliker, M. Winzeler, M. Gygax, A. Hund, and A. Einsele. Revue Suisse d'àgriculture 40(5):283-288 (2008), in French.

http://www.db-acw.admin.ch/xtrdb/qform.php?next=result&Structures=*!2.12.37.601.*&Sprache=*FR*&qname=pubSearch&sort=Zeitschrift⟨=fr

Abstract:

Basic conditions for plant production in Switzerland will be substantially different by 2050, mainly by increased competition in global and free markets, climate change causing more frequent disasters, and by scarcity of resources: soil quality will diminish, arable land will disappear and water will no longer be constantly available. Is plant production in Switzerland still feasible and expedient under these circumstances? What are the requirements for plant production in the future? Experts in plant sciences addressed these questions during the project "Perspectives for Plant Production 2050" of the Swiss Society of Agronomy (SSA). The conclusions of the study showed that the sufficient production of high quality food is only

in the literature

possible based on scientific and technological progress in plant sciences and production. In addition, conservation of fertile agricultural land and public commodities such as recreational landscapes, secure supply of drinking water and conservation of biodiversity are a necessity. The SSA highlights the requirements for research and development for enabling plant production of high quality and quantity in the future. ■

Effect of N and K Fertilizers on Yield and Quality of Greenhouse Vegetable Crops. Liu, Z.H., L.H. Jiang, X.L. Li, R. Härdter, W.J. Zhang, Y.L. Zhang, and D.F. Zheng. Pedosphere 18(4):496-502 (2008).

http://dx.doi.org/10.1016/S1002-0160(08)60040-5

Abstract:

The application of large amounts of fertilizers, a conventional practice in northern China for the production of vegetable crops, generally leads to substantial accumulation of soil nutrients within a relatively short period of time. A fixed field experiment was designed to study the effects of nitrogen (N) and potassium (K) fertilizers applied to optimize the yield and quality of typical vegetable crops. Application of N and K fertilizers significantly increased the yields of kidney bean. The largest yields were obtained in the first and second years after application of 1,500 kg N and 200 kg K_2O/ha. In the third year, however, there was a general decline in yields. Maximum yields occurred when intermediate rates of N and K (750 kg N and 300 kg K_2O/ha) were applied. However, no significant differences were observed in the concentrations of vitamin C (VC) in kidney bean among different years and various rates of fertilizer treatments. Yields of tomato grown in rotation after kidney bean showed significant responses to the application of N and K in the first year. In the second year, the yields of tomato were much lower. This suggested that the application of N fertilizer did not have any effect upon tomato yield, whereas application of K fertilizer did increase the yield. Application of K fertilizer was often associated with increased sugar concentrations. ■

Potassium Fertility and Terrain Attributes in a Fragiudalf Drainage Catena. Winzeler, H.E., P.R. Owens, B.C. Joern, J.J. Camberato, B.D. Lee, D.E. Anderson, and D.R. Smith. Soil Sci. Soc. Am. J. 72:1311-1320 (2008).

http://soil.scijournals.org/cgi/content/abstract/soilsci;72/5/1311

Abstract:

Site-specific management of soil fertility has been based on soil sampling in grid patterns or within soil mapping units without taking full advantage of terrain–soil relationships. The goal of this study was to determine whether terrain attributes relate significantly to soil K availability. The topographic wetness index (TWI), a terrain attribute that comprises the upstream contributing area and the slope for a portion of land, relates to soil wetness. We evaluated Mehlich-3 K (M3K), plant-available nonexchangeable K (PANK) with a modified tetraphenylboron extraction, effective cation exchange capacity (ECEC), and other soil variables from soil samples taken at three depths, and terrain attributes in a 3.6-ha farmed site in the Cincinnati catena, a major toposequence in the Muscatatuck Uplands region of Indiana. The PANK and M3K were significantly ($P < 0.0001$ and $P < 0.05$, respectively) related to TWI and relative elevation in models with anisotropic spatial autocorrelation variance estimates in three dimensions (latitude, longitude, and soil depth). The PANK and M3K increased with decreasing TWI in the following drainage class order: poorly < somewhat poorly < moderately well drained. The M3K decreased with soil depth, while PANK increased. The PANK/M3K ratio was significantly higher in the poorly drained soils than in the moderately well-drained soils, implying greater mobility or weathering of K in wetter soils. The ECEC also related strongly to terrain attributes ($P < 0.0001$ for relative elevation, TWI, and interaction effects). Possible mechanisms include lateral downslope lessivage and K leaching. Terrain attributes can aid in soil K fertility evaluations on the Cincinnati catena because they relate well to soil K fertility measurements. ■

Effect of Potassium and C/N Ratios on Conversion of NH^+_4 in Soils. Tang, Y., X.Z. Wang, H.T. Zhao, and K. Feng. Pedosphere 18(4):539-544 (2008).

http://dx.doi.org/10.1016/S1002-0160(08)60045-4

Abstract:

Two soils, one consisting of 1:1 clay minerals at pH 4.5 and the other containing 2:1 clay minerals at pH 7.0, were used to estimate the conversion of added NH^+_4 under different C/N ratios (glucose as the C source) and the addition of potassium. Under lower C/N ratios (0:1 and 5:1), a large part of the added NH^+_4 in the acid soil was held in the forms of either exchangeable or water soluble NH^+_4 for a relatively long time and under higher C/N ratio (50:1), a large amount of the added NH^+_4 was directly immobilized by microorganisms. In the second soil containing appreciable 2:1 type clay minerals a large part of the added NH^+_4 at first quickly entered the interlayer of the minerals under both lower and higher C/N ratios. In second condition, however, owing to microbial assimilation stimulated by glucose the newly fixed NH^+_4 could be completely released in further incubation because of a large concentration gradient between external NH^+_4 and fixed NH^+_4 in the mineral interlayer caused by heterotrophic microorganisms, which

K in the literature

imply the fixed NH^{+}_{4} to be available to plants. The results also showed that if a large amount of K+ with carbon source together was added to soil, the higher K+ concentration of soil solution could impede the release of fixed NH^{+}_{4}, even if there was a lot of carbon source. ■

Variability of Soil Properties, Early Phosphorus and Potassium Uptake, and Incidence of Pests and Weeds in Relation to Soybean Grain Yield. Sawchik, J., and A.P. Mallarino. Agron. J. 100:1450-1462 (2008).

http://agron.scijournals.org/cgi/content/abstract/agrojnl;100/5/1450

Abstract:

Successful crop management requires understanding relationships between site characteristics and crop yield. We studied intercorrelations among soil and crop properties using factor analysis (FA) and principal components analysis (PCA), and their relationships with soybean [Glycine max (L.) Merr.] within-field yield variability. Site variables (22) measured on 0.2-ha cells of 12- to 20-ha areas of five Iowa fields were: elevation; soil texture; extractable nutrients; incidence of soybean cyst nematode (Heterodera glycines) (SCN), diseases, and weeds; soybean dry weight (DW), height, and P and K uptake at V5; plant height at R5; and grain yield. Agronomic interpretations of interrelationships among site variables were more straightforward for FA than for PCA. The factors conditions for early growth and nutrient uptake and intrinsic soil properties were present in all fields, plant P and K availability was present in three fields, and the factor soybean pests, weeds or plant growth was present in the other fields. Factor analysis and PCA accounted for 62 to 64 per cent of the yield variability in the field with the largest yield CV (30%) and 5 to 35 per cent in the other fields (CV 2.8 to 5.9%). Two factors related significantly to yield in two fields (plant P and K availability and intrinsic soil properties) while others were specific to one field. Factor analysis identified groups of interrelated site variables, showed how they accounted for yield variability, and showed that single measurements seldom account for most yield variation in a field. ■

Combining Organic and Mineral Fertilizers for Integrated Soil Fertility Management in Smallholder Farming Systems of Kenya: Explorations Using the Crop-Soil Model FIELD. Tittonell, P., M. Corbeels, M.T. van Wijk, B. Vanlauwe, and K.E. Giller. Agron. J. 100:1511-1526 (2008).

http://agron.scijournals.org/cgi/content/abstract/agrojnl;100/5/1511

Abstract:

Integrated soil fertility management (ISFM) technologies for African smallholders should consider (i) within-farm soil heterogeneity; (ii) long-term dynamics and variability; (iii) manure quality and availability; (iv) access to fertilizers; and (v) competing uses for crop residues. We used the model FIELD (Field-scale resource Interactions, use Efficiencies and Long term soil fertility Development) to explore allocation strategies of manure and fertilizers. Maize response to N fertilizer from 0 to 180 kg N ha^{-1} (±30 kg P ha^{-1}) distinguished poorly responsive fertile (e.g., grain yields of 4.1–5.3 t ha^{-1} without P and of 7.5–7.5 t ha^{-1} with P) from responsive (1.0–4.3 t ha^{-1} and 2.2–6.6 t ha^{-1}) and poorly responsive infertile fields (0.2–1.0 t ha^{-1} and 0.5–3.1 t ha^{-1}). Soils receiving manure plus fertilizers for 12 yr retained 1.1 to 1.5 t C ha^{-1} yr^{-1} when 70% of the crop residue was left in the field, and 0.4 to 0.7 t C ha^{-1} yr^{-1} with 10% left. Degraded fields were not rehabilitated with manures of local quality (e.g., 23–35% C, 0.5–1.2% N, 0.1–0.3% P) applied at realistic rates (3.6 t dm ha^{-1} yr^{-1}) for 12 yr without fertilizers. Mineral fertilizers are necessary to kick-start soil rehabilitation through hysteretic restoration of biomass productivity and C inputs to the soil. ■

Read on:

- **Crop Residue Management for Lowland Rice-Based Cropping Systems in Asia**. Bijay-Singh, Y.H. Shan, S.E. Johnson-Beebout, Yadvinder-Singh, and R.J. Buresh. 2008. Advances in Agronomy, 98, pp 117-199. ISSN 0065-2113, DOI: 10.1016/S0065-2113(08)00203-4.
- **Nitrogen uptake, fixation and response to fertilizer N in soybeans: A review.** Salvagiotti, F., K.G. Cassman, J.E. Specht, D.T. Walters, A. Weiss, and A. Dobermann. 2008. Field Crops Research, 108, pp 1-13.
- **Organic agriculture cannot feed the world.** Connor, D.J. 2008. Field Crops Research, 106, pp 187-190.
- **Sugarcane for Bioethanol: Soil and Environmental Issues.** Hartemink, A.E. 2008. Advances in Agronomy, 99, pp 125-182. ISSN 0065-2113, DOI: 10.1016/S0065-2113(08)00403-3.
- **Crop research a target of international investment.** Nature, 456, 14 (2008). DOI: 10.1038/456014e. http://www.nature.com/news/2008/081105/full/456014e.html ■

For more K literature go to www.ipipotash.org/literature/

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IPI new Coordinator

Dr. Baladzhoti Tirugnanasotkhi has been nominated as the IPI Coordinator for East India, Bangladesh and Sri Lanka, effective 17 September 2008.

Dr. Tirugnanasotkhi holds the post of Professor at the Department of Agro-Chemistry, Soil Science and Agro-Ecology, Faculty of Agriculture, the Russian Peoples' Friendship University, Moscow. He will devote much of his time to working in the region, leading IPI activities.

Dr. Tirugnanasotkhi's MSc thesis focused on the "Effect of mineral nutrition on the electrophysiological parameters of sugar cane, in its early stage of growth", and his PhD thesis on "Comparative study of malsekko and anthracnose infections on citrus and action of some systemic fungicides in multiple nutritional levels, on the basis of electrophysiological reactions of tissues". In his current research, he is involved in projects dealing with the effects of ecological factors on human physiology in different farming areas in Russia, and control of plant stress by nutrition programming in different climatic conditions.

Besides his research, Dr. Tirugnanasotkhi has been involved in various agricultural projects in Africa. He is fluent in English, Tamil and Russian.

His knowledge and experience in managing international projects and in agronomic research will be a key factor in his ability to successfully lead IPI activities in the region. East India, Bangladesh and Sri Lanka are regions with high nutrient demand and high imbalance in the use of potash. Projects led by Dr. Tirugnanasotkhi will demonstrate the benefits of balanced fertilization in achieving higher yields and quality of agricultural produce, improved income to farmers, as well as higher environmental stewardship.

Dr. Tirugnanasotkhi can be contacted at t.baladzhoti@ipipotash.org, c/o International Potash Company, P.O. Box 468, 119034 Moscow, Russia, Mobile: +7 926 797 97 35, Fax: +7 499 724 86 53. ■

Dr. Baladzhoti Tirugnanasotkhi is welcomed at the Ch. Charan Singh (CCS) Haryana Agricultural University, Regional Research Station in Bawal, Haryana, during the meeting and discussions for the IPI-CCS HAU project, 2004-2008. Photo by IPI.

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