4R Potassium Management in Apple Production in North China

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Although selection of K fertilizer source often shows little agronomic differences, **demonstrated gains due to better rate, timing, and placement of K are clearly worth exploring** for the apple growers in northern China.

Apple orchard in Shaanxi. Apple is one of the main fruits in China, with a production area of about 2.3 million (M) ha producing 40 M t, which accounts for 25% of the total national fruit production.

In northern China, the provinces of Shaanxi, Shandong, Hebei, Henan, Gansu, and Liaoning contribute to more than 80% of the country's total apple orchard area (MOA, 2013) making it one of the main cash crops for the region's farmers. Potassium is a very important nutrient for apples because of its well-known effects on fruit quality and storage.

Potassium's role as a "quality element" is well known. If soil K is limiting, plant processes including photosynthesis, respiration, sugar translocation, and numerous enzymes are impaired, which ultimately impacts the quality of any harvested product. In apple, sufficient K supply can increase fruit sugar content, improve fruit color and flavor (Wang et al., 2002; Zhang et al., 2007). Potassium also has significant impacts on apple fruit hardness, soluble solids, and titratable acid (Zhang et al., 2014) and shelf life (Yoshioka et al., 1989). In this latter case, maintaining an adequate and balanced soil K supply in apple orchards is critical. Excessive K input can limit the plant-availability of Ca (a competing cation), which is a condition associated with the development of the physiological fruit disorder called "bitter pit".

Based on the research data conducted in northern China by the IPNI China program, 4R K management (i.e., applying the right K source, at the right rate, time, and place) has an important role to play in enhancing the effectiveness of K inputs to the region's apple orchards.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca = calcium; KCl = potassium chloride; K_2SO_4 = potassium sulfate; FYM = farmyard manure.

Right Source

The most commonly used K sources in China's apple orchards are KCl and K_2SO_4. KCl commonly has a lower market price than K_2SO_4, and when applied at the same rate can reduce input cost and improve economic benefit. Besides the economic advantage, apple often responds to KCl. Studies in Shandong showed that in a 15-year old orchard, basal application of KCl at 0.6 kg K_2O/plant in spring increased fruit yield by 17% compared with a no K application (Tang, 2007). A five-year experiment in Shaanxi indicated that basal application of KCl at 0.25 kg K_2O/plant in the fall increased fruit yield of a 13-year old orchard by 22% and also improved fruit hardness and soluble solid content (Zhao et al., 2009).

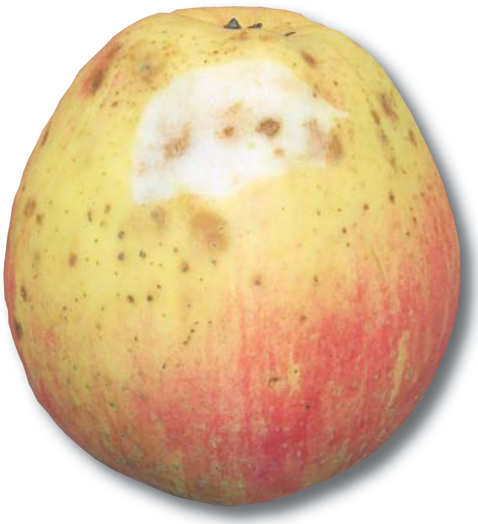
Comparing KCl and K_2SO_4, Chen et al. (2006) indicated that K_2SO_4 had a better effect on fruit yield than KCl at the same rate of K_2O, while Tang (2007) showed that K_2SO_4 produced less first-class fruit, and fruit had less soluble sugar and a higher sugar/acid ratio compared with trees receiving KCl. Field research from IPNI in three locations in China has found no significant difference between these K sources on fruit yield or quality (**Table 1**).

Right Rate

Apple researchers in China generally recommend a 2:1:2 ratio for $N:P_2O_5:K_2O$ application, but in practice the recommended rate for apple is complicated by a number of factors including tree-age, yield potential, tree density, climate conditions, soil nutrient status, and water management. Thus, recommendations vary significantly by region. The general recommendation for Fuji orchards has been based on the nutrient requirement needed to produce 100 kg fruit (Xi, 2006), i.e., 0.8-0.56-0.64 kg $N-P_2O_5-K_2O$/ha plus 200 kg FYM/ha. Therefore in practice, a fruit yield of 60 t/ha would require about 384 kg K_2O/ha plus 120 t/ha of manure. In a study in the Weibei arid region of Shaanxi, Liu et al. (2008) found application of 500-250-417 kg $N-P_2O_5-K_2O$/ha for Fuji orchards yielding 30 t/ha to be balanced. In Shandong, Hao et al. (2012)

Table 1. Effect of K sources on fruit yield and quality.						
Location	K source	Fruit yield, t/ha	Titratable acid, %	Firmness, kg/cm^2	Soluble solid, %	K conc., g/kg dry weight
Liaoning	-K	56.5 b	0.37 a	7.90 b	11.30 b	7.07 a
	KCl	66.5 a	0.37 a	8.40 a	12.60 a	6.73 a
	K_2SO_4	66.1 a	0.36 a	8.60 a	11.50 b	6.93 a
Shandong	-K	46.1 b	0.83 a	7.22 a	10.80 b	4.45 b
	KCl	48.4 a	0.78 a	7.41 a	12.04 a	5.18 a
	K_2SO_4	48.7 a	0.78 a	7.17 a	11.88 a	5.47 a
Shaanxi	-K	66.7 b	0.27 a	11.08 a	12.70 a	6.63 a
	KCl	90.0 a	0.30 a	9.84 a	12.30 a	7.46 a
	K_2SO_4	80.1 a	0.24 a	9.42 a	11.46 a	6.74 a

Notes: Two-year average fruit yields. Fertilizer K applied at the equivalent rate of 0.30 kg K_2O/plant. Quality indices were tested in the second year of the experiments. Numbers followed by different letters in the same column at the same location indicate significant difference at $p<0.05$.



A case of bitter pit in apple, caused by an imbalanced supply of Ca relative to K.

recommended 0.7-0.35-0.7 kg N-P_2O_5-K_2O/ha for each 100 kg of fruit production.

Application rates can also be based on estimates of K removal by fruits, leaves, and pruned branches. Examining orchards in Liaoning, Shandong, and Shaanxi, IPNI found the two-year average K removal by these respective plant parts to fall between 208 to 274, 74 to 84, and 116 to 148 kg K_2O/ha/yr, respectively. Theoretically, to keep balance, at least this amount of removal should be compensated for. However, in low K fertility soil, the K recommendation should be higher than removal in order to adequately buildup soil K concentrations.

Field trials with various rates of potash can also be used to determine the right rate of K. IPNI studies in Liaoning, Shandong, and Shaanxi found the economic optimum application rate for KCl to be 658, 400, and 583 kg K_2O/ha (i.e., 0.79, 0.45, and 0.35 kg K_2O/tree), while the rate for maximum yield was 674, 445, and 583 kg K_2O/ha (i.e., 0.81, 0.50, and 0.35 kg K_2O/tree), respectively (**Figure 1**). These results support the work by Jin et al. (2007), who found 600 kg K_2O/ha (0.36 kg K_2O/tree) to be appropriate in a 10-year Fuji apple orchard in Shaanxi. Similarly, Feng (2015) found 660 kg K_2O/ha (0.44 kg K_2O/tree) could produce maximum yield for Fuji apple in Liaoning.

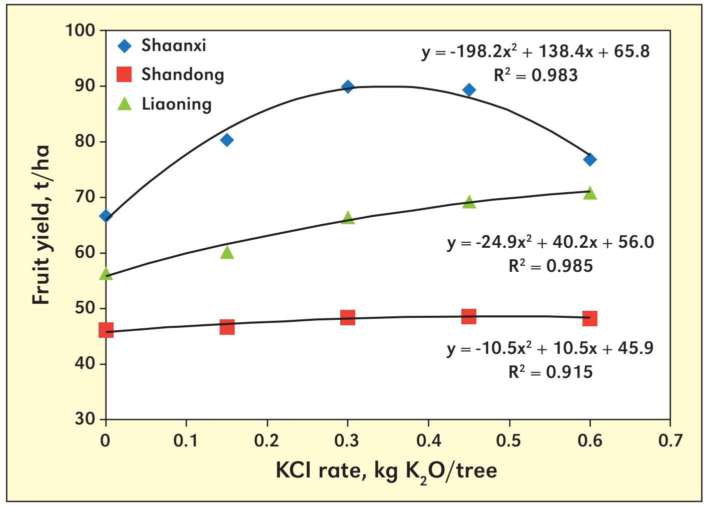


Figure 1. Relationship between the KCl application rate and apple (Fuji) fruit yield. IPNI Collaborative Research.

Right Time

Generally, apple trees take up soil nutrients after harvest until winter, storing these reserves to guarantee sufficient nutrient supply for young sprouts early the following year. Nutrient uptake increases after flowering and reaches a peak between fruit expansion and maturity (Fan et al., 2007). Thus, K nutrition during the late stages of growth are critical to fruit yield and quality.

Applying half or all of the K recommendation during the flowering and fruit expansion stages can produce more fruit than if the total K application occurs at the start of the season as a basal application (**Table 2**). A separate study by Lu et al. (2015) also found that split application of K increased fruit yield by 20 to 28% compared with a single basal application, and that the right time for K application was a 50:50 split applied first as basal application and then at the fruit expansion stage. However, large K applications late in the season can have a negative effect by reducing fruit Ca content, increasing the fruit K/Ca ratio, and reducing fruit firmness (**Figure 2**). In research by IPNI, this effect was most apparent in Liaoning and Shaanxi (**Table 2**). This information highlights the need to monitor Ca nutrition when applying K fertilizers as is may be necessary to supplement orchards with Ca.

Right Place

The horizontal root system of apple trees is mainly distributed within the area occupied by the tree crown, with roots distributed within a 20 to 50 cm depth. This is favorable for nutrient uptake when fertilizers were applied in the root zone. In China's orchards, three approaches are used for fertilizer placement including: (i) a circular furrow, (ii) a strip furrow, and (iii) radial fertilization from the tree trunk. The correct application method is dependent on tree age, density, fertilizer source, and time of application. For young orchards with less density, the recommendation is a basal application of fertilizer mixed with decomposed manure, which is placed in a circular furrow 40 to 50 cm wide, 30 to 40 cm deep, and 20 to 30 cm away from tree crowns. For high density orchards, strip furrow application is recommended using a 40 to 50 cm wide and 40 to 50 cm deep furrow placed along the tree row 20 to 30 cm away from tree crown. The furrow is usually done

Table 2. Effect of KCl application time on fruit quality indices.

Location	Timing of K application	Fruit yield, t/ha	Firmness, kg/cm^2	K conc., g/kg dry weight	Ca conc., g/kg dry weight	K/Ca ratio
Liaoning	-K	58.0 c	7.90 d	7.07 a	1.03 a	6.9
	100% B	68.4 b	9.00 a	6.80 b	0.93 a	7.3
	50% B+50% FE	72.4 a	8.80 ab	7.03 a	0.93 a	7.6
	50% FL+50% FE	70.3 ab	8.60 bc	7.03 a	0.97 a	7.2
	100% FE	68.1 b	8.57 c	6.83 b	0.50 b	13.7
Shandong	-K	45.4 b	7.26 a	5.07 c	0.47 ab	10.8
	100% B	48.2 a	7.30 a	5.33 ab	0.43 bc	12.4
	50% B+50% FE	49.7 a	7.30 a	5.48 a	0.43 ab	12.7
	50% FL+50% FE	48.1 a	7.30 a	5.26 bc	0.39 cd	13.5
	100% FE	47.1 a	7.32 a	5.27 b	0.38 d	13.9
Shaanxi	-K	67.0 b	11.08 ab	7.63 a	1.17 a	6.5
	100% B	68.1 b	10.95 ab	9.01 a	0.97 ab	9.3
	50% B+50% FE	77.7 a	11.31 a	7.52 a	1.02 a	7.4
	50% FL+50% FE	84.1 a	10.13 ab	8.01 a	1.15 a	7.0
	100% FE	82.6 a	8.97 b	8.56 a	0.71 c	12.1

Notes: Two-year average fruit yields. B: basal application, FE: fruit expansion, FL: flowering. Numbers followed by different letters in the same column at the same location indicate significant difference at $p<0.05$. IPNI Collaborative Research.

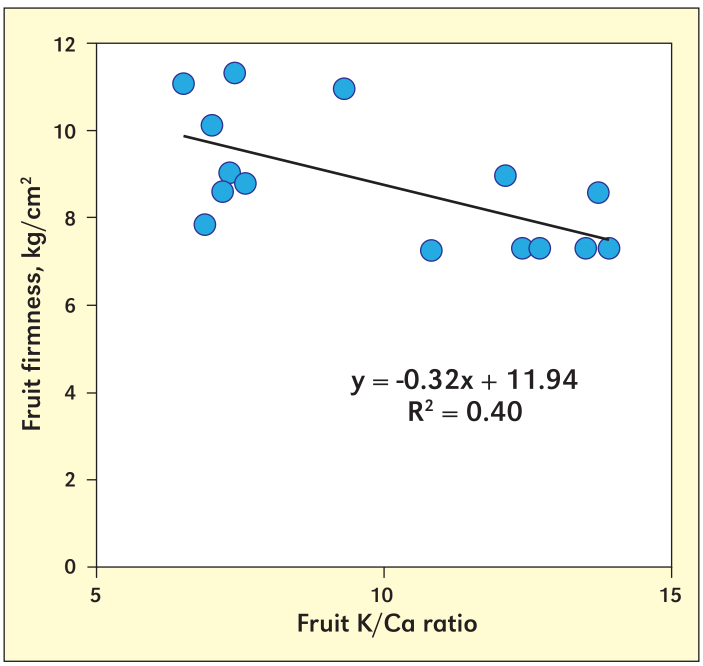


Figure 2. Relationship between fruit K/Ca ratio and apple fruit firmness. IPNI Collaborative Research.

by a trenching machine. For full-grown trees with low density, radial fertilization is recommended using 3 to 6 radial furrows around the tree trunk (20 to 40 cm wide, 20 to 40 cm deep, with a 0.5 to 1.0 m length), placed 50 cm away from trunk. In all three fertilizers can be applied in shallow soil layer (20 to 30 cm) when topdressing. Care should be taken to avoid damage to tree roots when digging, and the furrows should be covered with soil after fertilizer application, and then irrigated.

Fertigation is another method to apply fertilizer K. Fertigation, through drip irrigation, can effectively apply soluble nutrients and has been shown to improve nutrient and water use efficiency. Raina et al. (2013) found 35% higher fruit yields and a 25% savings on irrigation water through drip fertigation compared to conventional fertilization with surface flood irrigation. It is recommended that orchards in northern China convert to fertigation based on the present water shortages and low fertilizer use efficiencies that are achieved with traditional irrigation practices.

Foliar application can also be used to supplement the supply of K at different growth stages. Foliar application of K_2SO_4 with other nutrients like Ca during the fruit expansion stage is a popular means to improve fruit yield and quality, and to prevent physiological diseases like bitter pit.

Summary

This article demonstrates the importance of K nutrition in apple production. There is little difference in the agronomic effectiveness of the commonly applied K sources. However, the right rate and balanced use of K fertilizer split between a basal pre-plant application and a topdressing during fruit expansion resulted in more yield and an improved quality apple. Proper K fertilizer placement depends on tree-age and planting density. Careful consideration of K management based on 4R principles can support higher yield and quality of apple. BC

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