5. Application of fertilizers

5.1. Application of solid fertilizers

5.1.1. Broadcast

Broadcasting consists of uniformly distributing dry or liquid materials over the soil surface, usually before sowing. The fertilizer maybe incorporated into the soil mechanically, or left on the surface to be washed in by rainfall or irrigation (CFA, 1995). Incorporation into the Ap horizon can be by harrow (2-3 cm depth), a cultivator (4-6 cm depth) or by plough (incorporation to plough depth) (Finck, 1982). Broadcasting is the simplest and cheapest method and is best suited for high-speed operations and heavy application rates, especially before planting.

5.1.2. Band

In order to achieve maximum efficiency, K fertilizer may be applied in localized bands at or just prior to planting. However, when not accurate, band placement can produce a large concentration of soluble salts in the deposition zone, leading to decreased germination and plant emergence due to severe plasmolysis (Mortdvedt *et al*., 1999). Fertilizer placed in a band below (5 cm) and to the side (5 cm) of the seed usually causes less damage during germination and seedling roots develop normally. Within a short period (2 weeks) and with enough soil moisture, the salt in and around the band diffuses into a larger volume of soil so that any hazard to plants no longer exists (Follet *et al*., 1981; Finck, 1982). The safe quantity of K that can be band placed depends on the crop.

Fertilizer can be applied with the seed by a double-disc or similar drill that places the seed and fertilizer in a very narrow band (Follet *et al*., 1981; Finck, 1982).

Band placement of K can be more efficient than broadcasting, especially where soil test levels are low, where early season stress from cool or wet conditions is likely to limit root growth and K uptake and for soils likely to fix a large proportion of the added K. A higher efficiency for banded rather than broadcast K for corn was reported, but the differences decreased as the soil test level of K increased (Follet *et al*., 1981). Other data for corn show that broadcast K was 33 to 88% as efficient as banded K when the soils tested low to medium in available K (Welch *et al*., 1966).

Banding of KCl is widely practiced under *no-till* management. The response to banded KCl was twice as large for no-till corn as for corn grown after fall plowing (Vyn *et al*., 1999).

5.1.3. Side or top dressing

Fertilizer is side or top-dressed when it is applied after the crop has emerged, and/or when the dose is split for two or more applications. Split applications can be beneficial in some cases, especially for annual crops with a long growing period.

Split application of KCl is also recommended for crops growing on low CEC soils, where K can be lost by leaching K following high rainfall or excess irrigation (Kafkafi *et al*., 1977; Mortdvedt *et al*., 1999). Soybean responded significantly up to 50 kg K ha^{-1} when applied half at planting and half at flower initiation, or applying one third at planting, one third at flower initiation and one third at pod development (Kolar and Grewal, 1994).

Splitting the K application is also used in orchards and for other perennial crops, especially for alfalfa and grasses (Follet *et al*., 1981). In trials in a commercial field of lucerne, the largest yields, up to 3.15 t ha^{-1} in 26 days, were on plots treated with 948 kg K ha^{-1} as KCl in 3 applications (Kafkafi *et al*., 1977).

In areas of Cl deficient soils, top-dressed applications of KCl for autumn sown small grains may be more effective than preplant applications because of the potential for Cl leaching from the root zone due to rainfall (Mortdvedt *et al*., 1999).

5.1.4. Equipment for solid potassium chloride application

5.1.4.1. Manual distribution

Potassium chloride can be applied manually, trained workers achieving approximately the correct amount and uniform application. A more advanced method consists in small portable centrifugal distributors operated by hand (Finck, 1982).

5.1.4.2. Mechanical distribution

Modern fertilizer spreaders range from simple centrifugal types with broadcasting widths of 24 m and more, to expensive pneumatic spreaders where each outlet accurately spreads over 2 to 3 m (Möller and Svensson, 1991) (Plate 5.1). Wide-sweep or full-width distributors can be of the box-type or centrifugal. In the drop or box-type distributor the fertilizer drops by gravity through the distributing device operated by slots, an endless-chain, rotating plates or grids at the bottom of the box. This type of distributor suits both fine or granulated fertilizers, and applies a fairly exact pattern limited to the distance between the wheels. The main disadvantage is the small working width, up to 5 m (McCarty and Sartain, 1995; Finck, 1982). In the centrifugal, rotary or cyclone distributor, the fertilizer drops from a conical

container onto a high-speed rotary disk with throwing bars. A baffle plate ensures that the fertilizer is spread in a semicircle only to the rear. The main advantage is the larger working width (12-14 m). The main disadvantages are that only granulated fertilizers can be spread; and they are harder to calibrate because heavier fertilizer particles are thrown farther away from the spreader (McCarty and Sartain, 1995; Finck, 1982).
Another type of distributor is the row distributor for precise application in plant rows using pneumatic systems (Svensson, 1994).

5.2. Foliar application

Foliar application involves the use of KCl in solution. It results in fast K absorption and utilization and has the advantage of quickly correcting deficiencies diagnosed by observation or foliar analysis. Other advantages are low application rates, and uniform distribution of fertilizer (Finck, 1982). However, foliar fertilization is supplementary to and cannot replace the basal fertilization.
Foliar application should be done during periods of low temperature and relatively high humidity, such in the early morning or late evening (Mortdvedt *et al*., 1999). Otherwise the salts may cause leaf burning and necrosis especially when applied in concentrations above those recommended (Marschner, 1995). Because of its osmotic action, KCl applied on leaves is not well tolerated by plants and so is not usually used for foliar application. Nevertheless, it can be beneficial in some cases.

5.2.1. Rice

A foliar application of 10 kg KCl m^{-3} to rice at panicle initiation, boot leaf and 50% flowering stages, both in the monsoon and winter seasons, significantly increased seed yield and improved quality (seed germination and 100-seed weight) (Jayaraj and Chandrasekharan, 1997). Splitting a total of 95 kg ha^{-1} of KCl to rice, a third at sowing in soil, a third as a foliar spray at flag leaf stage and a third as foliar spray at grain development, gave larger yields than a soil application all at sowing (Narang *et al*., 1997).
A foliar spray applying 3.9 kg K ha^{-1} (as 10 kg KCl m^{-3}) three times at one week intervals from full head of rice cv. *Wuyuegen* increased grain yield from 7850 kg ha-1 in the control plots, sprayed only with water, to 8500 kg ha-1 (Xu and Bao, unpublished results). It is unclear whether K or Cl contributed to the increased grain yield. The response of rice and other annual grain crops to KCl at the middle to later growing stages should be further studied.
In Tamil Nadu (India), on the paddy soils of the Cauvery Delta, it is recommended to apply two foliar sprays of diammonium phosphate (DAP) at

a rate of 20 kg m^{-3} with 10 kg m^{-3} of urea and KCl, one at panicle initiation and the other at 10% flowering. This may increase yields up to 0.75 t ha^{-1} (Nagarayan, 1999).

5.2.2. Wheat and corn

Narang *et al.* (1997) tested the response of wheat to three equal applications of a total of 95 kg KCl ha^{-1} (one third at sowing in soil, one third as foliar spray at the flag leaf stage and one third as foliar spray at grain development), compared to applying all K in soil at sowing. The response depended on the amount of KCl applied in to previous crop.

A foliar spray of KCl at rates between 5 and 20 kg Cl ha^{-1} at flag leaf emergence reduced *Septoria nodorum* diseases of winter wheat on the second leaves from the apex at anthesis, but yield was not increased, probably because the disease occurred too late to effect yield (Kettlewell *et al*., 1990).

Foliar spray of 10 kg KCl m^{-3} and 10 kg urea m^{-3} from the jointing stage of both corn and wheat to silking of corn and the full heading stage of wheat increased the N and K content in the plants and stimulated N translocation to the grain (Fig. 5.1.), increasing the protein content of wheat and corn grain by 15 g kg^{-1} and 4.9 g kg^{-1}, respectively (Table 5.1). However, only the grain yield of wheat was significantly increased by the foliar spray (Xu *et al*., 1999). More effective treatments are needed to improve disease control and obtain yield enhancement (Kettlewell *et al*., 1990).

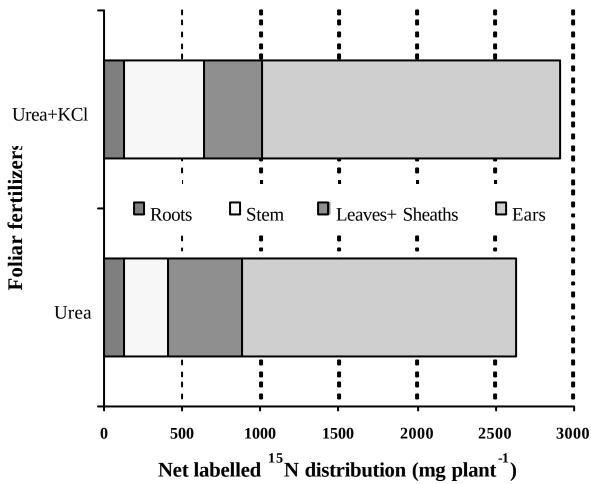

Fig. 5.1. Effect of combined foliar feeding with KCl and ^{15}N labelled urea applied at silking stage of corn on the distribution of ^{15}N in different organs at harvest (Xu *et al*., 1999).

Table 5.1. Effect of foliar feeding with urea and KCl on grain yield and protein content of corn and wheat.

Treatment	Winter wheat						Corn					
	Grain yield (mg ear $^{-1}$)		1000 grain weight (g)		Grain protein (g kg^{-1})		Ear yield (g DW plant^{-1})		Grain yield (g DW plant^{-1})		Grain protein (g kg^{-1})	
Control (water)	1125	a[a)]	42.1	a	134	a	1668	a	68.4	a	84.2	a
10 kg urea m^{-3}	1159	a	42.1	a	152	b	1763	a	72.8	a	88.6	b
5.4 kg KCl m^{-3}	1202	ab	44.0	b	144	ab	1703	a	71.6	a	83.4	a
10 kg urea m^{-3} + 5.4 kg KCl m^{-3}	1222	b	44.8	b	149	b	1776	a	74.9	a	89.1	b

a) Different letters represent significant differences at 5% probability.
Source: Xu *et al*. (1999).

5.2.3. Other crops

Groundnut: Foliar application of both KCl and K_2SO_4 significantly increased tissue % K and pod yield of groundnut grown on highly calcareous vertic-ustochrept soils with 188 kg ha^{-1} of NH_4OAc extractable K, as compared to the control and water spray (Umar *et al*., 1999). The higher leaf % K and pod yield obtained with 10 kg KCl m^{-3} than with 10 kg K_2SO_4 m^{-3} foliar application was due to the fact that the plants tended to accumulate more K when given KCl than K_2SO_4. No visual symptoms of leaf burn were detected with either foliar application.

Cotton: A 3-year field comparison of foliar application of the major K fertilizers conducted in Arkansas (Miley and Oosterhuis, 1994), showed a trend for KNO_3 to increase the yield and boll weight, followed by K_2SO_4 and $K_2S_2O_3$. KCl had no effect on yield and on boll weight. No visual symptoms of foliar burn were observed following foliar application of any of the K fertilizers. Experiments in Tennessee showed that yields from four K sources (KCl, K_2SO_4, KNO_3 and $K_2S_2O_3$) averaged 10% more than the untreated check, and yields with KNO_3 were 4% higher than the other K sources (Howard *et al*., 1998). Field tests in the USA Cotton Belt comparing KNO_3 and KCl, showed that KCl either had no effect on yield or it decreased it, in the later case this was probably due to its higher salt index (Oosterhuis, 1999). This author concluded that results on K foliar applications in the Cotton Belt have been variable and unpredictable, and that additional research was needed to fully explain the results.

Coffee: N:K imbalance in the leaf was corrected by a foliar spray of 1.5% KCl either once a month or once every two months. The additional KCl increased coffee berry yield and the percentage of parchment and clean coffee seeds. The foliar sprays also significantly increased the quality and size of the clean coffee seeds, and leaf N, P and K concentrations at harvest (Devarajan *et al*., 1990; 1991).

Sugarcane: In field trials in 1989-92 in South India, cane and sugar yields and N, P and K uptake were highest with a combination of KCl applied to the soil and a 1% KCl foliar spray (Subramanian, 1994). Channabasavanna and Setty (1994) reported that the application of 1.5% KCl as a spray helped induce drought hardiness in the developing cane thus alleviating water stress, and that commercial cane sugar yield was increased by applying extra K.

5.3. Fertigation

The need to increase yields per hectare, as well as the increasing shortage of irrigation water, fuels the development of efficient irrigation systems, i.e. pressurized irrigation methods (drip, jets, microjets, etc). These new

techniques pose new challenges and opportunities because both water and nutrient supply to the crops can be controlled easily.
While in flood irrigation there is full coverage of the soil with the irrigation water; the new irrigation methods are characterized by relatively small wetted areas: about 20-40% in drip systems and 40-60% in various micro-jets systems. Clearly, with the limited area of wetted soil, broadcasting fertilizers is inefficient. This led to the development of the *fertigation* technique, which combines the application of irrigation water with water soluble fertilizers. A simultaneous application of N, P and K, as a nutrient solution, through the irrigation system not only increases yields and improves quality, but also increases fertilizer use efficiency.
In Israel, approximately 80% of the irrigated area use fertigation. In 1996, the Israeli farmer used, on average, 115 kg N, 46 kg P_2O_5 and 57.5 kg K_2O ha^{-1}. Over 50% of the N and P_2O_5, and 65% of the K_2O was applied by fertigation (Tarchitzky and Magen, 1997).

5.3.1. Advantages of fertigation

Fertigation applies nutrients exactly and uniformly only to the wetted soil, where the active roots are concentrated. This maximizes nutrient utilization and lessens the potential for groundwater pollution caused by nutrient leaching. Nutrient application can be adapted throughout the growing season to meet the changing nutritional requirement of the crop according to its physiological stage, to achieve maximum yield and quality (Scaife and Bar-Yosef, 1995). Fertigation schemes, which are specific for the crop, soil and climate, are especially relevant for K, which can be supplied at adequate rates during the reproductive stages of vegetables and fruit trees.
Other advantages of fertigation are: (1) saving of energy and labor, (2) flexibility in the time of application: nutrients can be applied when crop or soil conditions would otherwise prohibit the use of wheeled application equipment, (3) there is no risk of foliar scorch and development of plant pathogens (4) convenient use of compound and ready-mix nutrient solutions which can also contain small concentrations of micronutrients, (5) the supply of nutrients can be more carefully regulated and monitored (Bar-Yosef, 1999).
In pressurized irrigation systems, fertigation is a necessity. It is considered that fertigation provides the only proper way to apply fertilizers physically to the crop root zone when the crop has to be irrigated (Burt *et al*., 1998). For a summary of numerous studies showing the advantages of fertigation (see Bar-Yosef, 1999).

5.3.2. Potassium fertilizers for fertigation

Common sources of K for fertigation are potassium chloride (KCl, fertigation grade), potassium nitrate (KNO_3), potassium sulphate (K_2SO_4, fertigation grade), monopotassium phosphate (KH_2PO_4), potassium thiosulphate ($K_2S_2O_3$) and potassium hydroxide (KOH). These K fertilizers are also used as ingredients in clear liquid N-P-K, N-K or P-K solutions. The K fertilizer is chosen according to its solubility, anion type, ease of use, price, existing equipment and area to be fertigated (Hagin and Lowengart-Aycicegi, 1999).

Potassium chloride is commonly used in fertigation of many crops: citrus, banana, deciduous orchards, maize, potato, cotton and other field crops, tomato and other vegetables grown in open fields, and sugarcane. In general, the exceptions are floriculture, glasshouse production, avocado orchards and other Cl sensitive crops.

Soluble grade or fertigation grades are used to avoid insoluble materials clogging the emmitters. These grades are specially manufactured, so that the dry fertilizer is 100% water soluble and forms a clear solution. Rug and Kahle (1990) studied the quality of KCl for fertigation, and concluded any conditioner should not exceed 150 mg L^{-1} (in the dry material), and the particle size range should be 0.15-0.6 mm to achieve rapid maximum dissolution. Only white KCl should be used because the iron impurities in the red or pink forms can clog emitters and filters.

If normal grade KCl has to be used, any scum formed by the coating and conditioning agents should be removed by skimming if it is at the surface, and if the scum settles in the container, then the clear liquid should be pumped, drained or siphoned from the top portion (Burt *et al*., 1998).

Potassium chloride can be used as solid when the KCl is poured into a by-pass tank, the irrigation water enters the tank dissolving the solid and goes out to the main line carrying the dissolved fertilizer. When used as a liquid, small volume stock solutions - prepared by farmers or in factory-prepared liquid fertilizers containing KCl - are injected by pumps into the irrigation line.

5.3.3. Solubility of potassium fertilizers

An essential pre-requisite for the use of solid fertilizers in fertigation is their complete dissolution in the irrigation water, and this depends on temperature (Table 5.2). Potassium chloride is the most soluble form up to 25°C. The solubility of KNO_3 increases sharply with temperature, but at ambient and lower temperatures, its solubility decreases very quickly and becomes significantly lower than that of KCl. K_2SO_4 is least soluble over the entire temperature range.

Taking into consideration the K content of each fertilizer, KCl gives the highest percent of K in the solution at each temperature (Table 5.3). This influences the volume of the storage tank required: at 10°C, the tank volume needed to prepare a KNO_3 or a K_2SO_4 solution must be twice or three times larger, respectively, than that required when KCl is used.

Table 5.2. Solubility of potassium fertilizers at different temperatures.

Temperature (°C)	KCl Solubility (g 100 g^{-1} water)	KCl t90[a] (minutes)	K_2SO_4[b] Solubility (g 100 g^{-1} water)	K_2SO_4[b] t90 (minutes)	KNO_3 Solubility (g 100 g^{-1} water)	KNO_3 t90 (minutes)
10	31	5.0	9	38.7	21	12.5
20	34	3.9	11	23.2	31	7.3
30	37	-	13	-	46	-

[a] t90 is defined as the time in minutes needed to dissolve 90% of the fertilizer.

[b] Normal grade K_2SO_4 (not fertigation grade) was used in this experiment.

Source: Elam *et al*. (1995).

Table 5.3. Amount of K_2O in saturated solutions of potassium fertilizers.

Temperature (°C)	KCl	K_2SO_4	KNO_3	KH_2PO_4
	---------------------- (kg K_2O m^{-3})	----------------------		
0	138	37	54	43
10	149	46	81	52
16	156	56	99	59
30	170	61	145	74

Source: Wolf *et al*. (1985).

5.3.3.1. Rate of dissolution

When comparing non-fertigation grades of KCl and K_2SO_4, the dissolution time of KCl is quicker than that of K_2SO_4 (Table 5.2), and temperature is less important for KCl than for the other K fertilizers (Elam *et al*., 1995).

5.3.3.2. Heat of dissolution

The heat of solution is the amount of heat per unit weight, either needed or produced when a material is dissolved in water (Kachelman, 1989). Most dry K fertilizers absorb heat from the water upon dissolution (Table 5.4), thus lowering the temperature of the solution (endothermic reaction). For example, under field conditions, it takes 4 minutes to fully dissolve and to prepare a 14% KCl solution, and the temperature drops from 10°C to 4°C (Lupin *et al*., 1996).

Table 5.4. Heat of dissolution of different fertilizers in water at 25°C.

Fertilizer concentration (kg m^{-3})	KCl	KNO_3	KH_2PO_4	NH_4NO_3	$(NH_4)_2SO_4$	Urea
	------------- Heat required (Kcal kg^{-1} solute) ------------					
50	55.6	78.6	33.8	74.7	14.2	59.7
100	54.1	74.5	33.0	71.2	13.3	58.6
150	52.3	71.6	32.3	69.2	12.8	57.5

Source: Wolf *et al*. (1985).

For solids with a negative heat of solution (such as KCl) in water it is important to know the salt-out temperature of the resulting solution (Table 5.5) because this determines the water temperature needed for complete dissolution of the fertilizer. For example, a KCl solution containing 14% K_2O has a salt-out temperature of 2.2°C, and the estimated minimum temperature for complete dissolution is 16.7°C for an estimated mixing time of <5 min (Kachelman, 1989).

Table 5.5. Salt-out temperature of KCl solutions.

K_2O content (g m^{-3})	100	110	120	130	140	150	160
Salt out (°C)	-7.8	-8.9	-10.6	-4.4	2.2	10.0	20.0

Source: Kachelman (1989).

Heats of solution data of the chemical compounds are useful when preparing nutrient solutions with different fertilizers. For example, the dilution of phosphoric acid is an exothermic reaction, resulting in a rise of the temperature of the solution. This can be used to minimize the endothermic reaction of urea or KCl (Lupin *et al*., 1996).

5.3.4. Solution preparation

Fertilizer solutions for fertigation can be prepared by various methods (Sneh, 1995): Solid fertilizers such as $(NH_4)_2SO_4$, urea, KCl, KNO_3 and K_2SO_4 and liquid H_3PO_4 can be mixed by the farmers to prepare a *tailor-made* stock solution. This stock solution is then injected into the irrigation system, at rates of 2-10 L m^{-3}, depending on the desired concentrations of N, P and K. In addition, solid soluble NPK mixtures are manufactured as solids for making solutions on the farm, with different ratios between the three major elements. Some compositions contain micronutrients in the form of chelates, mainly EDTA.

Ready-made liquid NPK solutions are also manufactured, having a total nutrient concentration of about 16-20% only (N, P_2O_5, K_2O).

Clear NK, PK and NPK fertilizer solutions with at least 9-10% nutrients (N, P_2O_5, K_2O) based on urea, phosphoric acid and KCl can be easily prepared on the farm with limited facilities and with minimal mixing (Lupin *et al*., 1996; see examples in Table 5.6). Application of 2 liters of a 3.6-3.6-3.6 (% N, P_2O_5 and K_2O) stock solution to 1 m^3 irrigation water, will give concentrations of 72 mg L^{-1} of N, P_2O_5 and K_2O, respectively.

5.3.5. Fertigation methods

There are two ways to control the injection of a fertilizer solution into the irrigation line (Plate 5.2):

5.3.5.1. Quantity

Field crops, orchards, plantations and/or crops grown on heavy clay soil are usually managed with the *quantitative* fertigation approach. The total quantity per unit area required by the crop is predetermined by leaf and/or soil analysis. This total amount is then divided into 5-10 applications during the irrigation season. From a simple *by-pass* tank containing the fertilizer, an appropriate volume is injected into the irrigation line. Both liquid and solid soluble fertilizers may be used with a *by-pass* tank. The advantages of this method are: its low cost, ease of installation and operation, and low maintenance requirements. The disadvantages are: the system is affected by water pressure changes, the concentration of the fertilizer varies during its application and it is not readily adapted to automated systems.

Table 5.6. Preparation of NPK stock solutions under field conditions (minimum stirring, 10°C), using urea, $(NH_4)_2SO_4$, H_3PO_4, KH_2PO_4 and KCl.

Type	N-P_2O_5-K_2O Ratio	Composition (% WT/WT)			Quantity added (kg m^3 tank)					Specific gravity	pH[a)]	EC[a) b)]
		N	P_2O_5	K_2O	Urea	AS	PA	MKP	KCl			(dS m^{-1})
NPK	1-1-1	3.3	3.3	3.3	72		53		54	1.080	3.3	0.300
	1-1-1	4.4	4.6	4.9	96			88	30	1.110	5.7	0.122
	1-1-3	2.4	2.4	7.3	52		39		120	1.110	3.6	0.360
	1-1-3	1.5	1.4	4.4		71		27	57	1.080	5.6	0.285
	1-2-4	2.2	4.8	8.9	48		77		146	1.140	4.3	0.490
	1-2-4	1.0	2.1	4.0		48		40	43	1.060	5.7	0.224
	3-1-1	6.9	2.3	4.3	150		37		70	1.070	4.3	0.200
	3-1-3	4.7	1.6	4.7	102		26		77	1.080	3.7	0.220
	3-1-3	2.9	1.0	3.0		138		19	38	1.100	6.2	0.393
	1-2-1	2.5	5	2.5	54		81		41	1.080	3.1	0.380
NK	1-0-1	4.6	0	4.6	100				75	1.070	6.2	0.160
	1-0-2	1.9	0	3.9		90			64	1.075	5.5	0.320
	1-0-3	2.5	0	7.5	54				123	1.090	5.1	0.240
	1-0-3	1.5	0	4.5		71			74	1.080	6.8	0.300
	2-0-1	5.8	0	2.9	126				48	1.050	4.8	0.090
	3-0-1	7.2	0	2.4	157				39	1.080	5.1	0.070
PK	0-1-1	0	5.8	5.8			94		95	1.090	2.7	0.450
	0-1-2	0	3.9	8				75	89	1.080	5.5	0.186
	0-1-3	0	2.9	8.7			47		143	1.120	3.4	0.360
	0-2-1	0	6.8	3.4			110		56	1.090	2.7	0.410
	0-1-4	0	2.4	9.6				46	131	1.060	5.7	0.249
K	0-0-1	0	0	7.5					123	1.060	6.7	0.220

AS: ammonium sulphate $(NH_4)_2SO_4$, PA: phosphoric acid H_3PO_4, MKP: monopotassium phosphate KH_2PO_4.

[a)] After dilution of 1:100.

[b)] EC: electrical conductivity at 25°C.

Source: Lupin *et al*. (1996).

5.3.5.2. Proportion

Greenhouse, soilless culture, and crops grown on light soils require a constant and controlled concentration of nutrients in the irrigation water. Fertilizers are added to the irrigation system by proportional injection of the fertilizer solution through a *Venturi* device or via pumps to keep a constant nutrient/water proportion. The advantages of such systems are: precise control of the quantity and injection timing, not affected by water pressure changes, they can be easily automated. The disadvantages are: high cost and maintenance and complicated operation. Sophisticated hydraulic or electric fertigation pumps controlled by computers are generally used in glasshouses and/or soilless culture with high value crops like vegetables or cut flowers.

5.3.6. Interaction between potassium fertilizers and irrigation water

Many water sources have high contents of Ca, Mg and bicarbonates (hard waters) resulting in pH values between 7.2 and 8.5. When fertilizers are added, precipitates can form in the fertilization tank and clog the drippers and filters. Addition of K_2SO_4 to hard waters may cause the precipitation of $CaSO_4$, clogging drippers and filters (Bar-Yosef, 1999), while addition of KH_2PO_4 may form precipitates of Ca and Mg phosphates. KCl and KNO_3 are the preferred forms of K because they do not pose any problems of clogging or precipitation, even with hard waters.
Recycled waters are particularly susceptible to precipitation due to their high bicarbonate and organic matter content.

5.3.7. Interaction between K fertilizers and other fertilizers (compatibility)

When preparing high concentrations solutions (stock solutions) for fertigation, the solubility products of the different materials must be taken into consideration. For example, the mixture of KCl and $(NH_4)_2SO_4$ in the tank considerably reduces the solubility of the mixture due to formation of K_2SO_4 precipitate. Other fertilizer mixtures which are not recommended are: calcium nitrate with any phosphates or sulphates, magnesium sulphate with di- or mono-ammonium phosphate, and phosphoric acid with iron, zinc, copper and manganese sulphates.
The use of two or more fertilizer tanks makes it possible to separate stock solutions of fertilizers that interact and cause precipitation. For example, using one tank for Ca, Mg and micronutrients compounds, and another for phosphates and sulphates compounds, enables safe and efficient fertigation.

5.3.8. Microbial plugging

A slime of bacteria and algae can also plug lines and emitters. When acid NPK fertilizers are used, the free Cl resulting from KCl in an acid solution may prevent the slime formed by Cl sensitive bacteria (Wolf *et al*., 1985).

5.3.9. Corrosion

Chemical reactions between fertilizer solutions (from acid fertilizers) and the metal parts in the irrigation system may cause corrosion of the metallic components and damage the cement and asbestos pipes (Wolf *et al*., 1985). In this aspect, KCl solutions have neutral pH and therefore no acidic reaction.
Chlorides in liquid mixtures corrode carbon steel at a slow rate, but the life expectancy of tanks made from such steel is at least 5 years and their life can be extended if they are periodically washed with water to lower the Cl level on the surface of the metal. When not in use, tanks should be filled to avoid the corrosive Cl-air combination (Potts, 1984).
Most of the stainless steel tanks are resistant to chloride corrosion, although 304 stainless steel is susceptible to Cl-induced pitting. PVC plastic is a good and relatively low cost material for pipes and tanks for fluid fertilizers (Potts, 1984).
Potassium chloride solutions should not be stored in tanks of non-ferrous metals other than stainless steel, unless coated with an anti-corrosion substance, usually paints (Wolf *et al*., 1985).

5.3.10. Fertigation with potassium chloride under saline conditions

Crops vary widely in their salt tolerance and detailed reference tables are available defining individual crop sensitivity to total soluble salts and individual toxic ions (Maas and Hoffman, 1977). When fertilizers are added to brackish waters for irrigation, they increase the EC of the irrigation water. However, the contribution of Cl from KCl to the total Cl in irrigation water is relatively small (Tarchitzky and Magen, 1997).
When the irrigation water is saline, and/or the crop is sensitive to salinity, the amount of accompanying ions added with K fertilizers must be decreased. For example, avocado is very sensitive to Cl, so other K fertilizers without Cl (KNO_3, K_2SO_4, etc.) are preferred to KCl. This avoids Cl accumulation in the soil solution and diminishes leaf burning caused by excess Cl. Also crops grown in containers in the glasshouse have a very restricted root volume, so fertilizers with a low salt index must be chosen, for example KH_2PO_4.
Correct irrigation management under saline conditions adds water in excess of the evaporation needs of the crop, so that the excess water will pass through and beyond the root zone and carry salts away with it, preventing salt accumulation in the root zone (Rhoades and Loveday, 1990).
More information on KCl management in irrigation is presented in detail in Chapter 6.

5.3.11. An example of fertigation program

A fertigation program consists in the application of nutrients and water throughout the crop cycle, in terms of daily or weekly quantities of nutrients and water. The program allows changes during the growing season, adjusting it to suit fruit, flower, shoot and root development, and external changes. A specific fertigation program is based on leaf and soil analysis and tailored to suit the actual crop requirements at a specific location.

A detailed fertigation program for field grown tomatoes for processing (the Extension Service of Israeli Ministry of Agriculture), is presented in Table 5.7. The fertigation program is based on the daily consumption of nutrients by the plant grown on a sandy loam soil, with a plant density of 11,000-12,500 plants ha^{-1} and an expected yield of 100 t ha^{-1}. The recommended amounts of each nutrient change according to the physiological stage of the crop, providing more P at the early growth and increasing the K during the final stages of fruit ripening. The nutrients can be provided either by NPK liquid or solid fertilizers, or the farmer can prepare his own nutrient solutions by mixing different fertilizers.

Table 5.7. Fertigation program for field grown tomatoes.

Physiological stage	Duration (weeks)	Nutrient ratio			Nutrient requirement (kg ha^{-1} day^{-1})		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O
Planting-Flowering	5	1	1	1	1.43	1.43	1.43
Flowering-Fruit set	4	1	0	2	2.50	-	5.00
Fruit set-Fruit ripening	4	1	0	1	3.21	-	6.43
Fruit ripening-Harvest	4	1	0	1.5	1.43	-	2.14
Total	16				250	50	430

- Plants are irrigated every 3-5 days in clay soils, and every 2-3 days in sandy soils. To calculate the fertilizer dose at each irrigation, multiply the daily amount of fertilizer by the days' interval between irrigation cycles.
- A base fertilization with P and K should be applied to the soil before planting according to soil analysis, using KCl and superphosphate.

Source: Extension Service, Ministry of Agriculture, Israel.

References

Bar-Yosef, B. (1999): Advances in Fertigation. *Adv. Agron.* **65,** 2-77.

Burt, C., O'Connor, K. and Ruehr, T. (1998): Fertigation. The Irrigation Training and Research Center. California Polytechnic State University, San Luis Obispo, CA. 295 pp.

CFA (California Fertilizer Association) (1995): Western Fertilizer Handbook. 8th ed. Interstate Publishers Inc., Danville, IL.

Channabasavanna, A.S. and Setty, R.A. (1994): Development of practices to overcome stress in sugarcane. *Farming Systems* **10**, 50-52.

Devarajan, E., Kulasekaran, M. and Arumugam, R. (1990): Studies to correct N:K nutritional imbalance in coffee. *South Indian Horticulture* **38**, 329-335.

Devarajan, E., Kulasekaran, M. and Arumugam, R. (1991): Studies on foliar nutrition of coffee. *South Indian Horticulture* **39**, 368-373.

Elam, M., Ben-Ari, S. and Magen, H. (1995): The dissolution of different types of potassium fertilizers suitable for fertigation. *In*: "Proceedings Dahlia Greidinger International Symposium on Fertigation". pp. 165-174. Technion, Haifa, Israel.

Finck, A. (1982): Fertilizers and Fertilization. Verlag Chimie GmbH, Weinheim, Germany.

Follet, R.H., Murphy, L.S. and Donahue, R.L. (1981): Fertilizers and Soil Amendments. Prentice -Hall Inc., Englewood Cliffs, NJ. 557 pp.

Hagin, J. and Lowengart-Aycicegi, L. (1999): Fertigation - State of the Art. The Fertiliser Society Proceedings 429. 24 pp. The International Fertiliser Society, York, UK.

Howard, D.D., Owen Gwathmey, C. and Sams, C.E. (1998): Foliar feeding of cotton: evaluating potassium sources, potassium solution buffering, and boron. *Agron. J.* **90,** 740-746.

Jayaraj, T. and Chandrasekharan, B. (1997): Foliar fertilization to enhance seed yield and quality in rice. *Seed Research*. **25**, 50-52.

Kachelman, D.L. (1989): Fluid Fertilizer Reference Manual. Bulletin Y-210, TVA/ NFDC 89/11. Tennessee Valley Authority, Muscle Schoals, AL.

Kafkafi, U., Gilat, R., Yoles, D. and Noy, Y. (1977): Studies on fertilization of field grown irrigated alfalfa. I. Effect of potassium source and time of application. *Plant Soil* **46,** 165-173.

Kettlewell, P.S., Bayley, G.L. and Domleo, R.L. (1990): Evaluation of late-season foliar application of potassium chloride for disease control in winter wheat. *J. Fert. Issue.* **7**, 17-24.

Kolar, J.S. and Grewal, H.S. (1994): Effect of split application of potassium on growth, yield and potassium accumulation by soybean. *Fertilizer Research* **39,** 217-222.

Lupin, M., Magen, H. and Gambash, Z. (1996): Preparation of solid fertilizer based solution fertilizers under "grass roots" field conditions. *Fertiliser News* (The Fertilizer Association of India) **41,** 69-72.

Maas, E.V. and Hoffman, G.J. (1977): Crop salt tolerance - current assessment. *J. Irrig. Drainage Div.* ASEC. **103,** 115-134.

Marschner, H. (1995): Mineral Nutrition of Higher Plants. 2nd ed. Academic Press, San Diego, NY.

Mc Carty, L.B. and Sartain, J.B. (1995): How to calibrate your fertilizer spreader. Fact Sheet ENH-62, Florida Cooperative Extension Service, University of Florida. 3pp.

Miley, W.N. and Oosterhuis, D.M. (1994): Comparison of five potassium fertilizers for foliar fertilization of cotton. *In:* "Proceedings of the 1993 Cotton Research Meeting and 1993 summaries of cotton research in progress". Special Report Agricultural Experiment Station, Division of Agriculture, University of Arkansas. No. 162, pp. 192-195. University of Arkansas Publications, Fayetteville, USA.

Möller, N. and Svensson, J.E.T. (1991): Modern techniques in application of granular fertilisers. The Fertiliser Society Proceedings 311. 40 pp. The Fertiliser Society, York, UK.

Mortvedt, J.J., Murphy, L.S. and Follett, R.H. (1999): Fertilizer Technology and Application. Meister Publishing Co. Willoughby, OH.

Nagarayan, R. (1999): Improving P nutrition on acid sulphate soils of the Mekong Delta. INMnet Bulletin 07/1999. p. 12. International Rice Research Institute, Philippines.

Narang, R.S., Mahal, S.S., Seema B., Gosal, K.S. and Bedi, S. (1997): Response of rice and wheat to K-fertilization under maximum yield research strategies. *Envir. Eco*. **15,** 474-477.

Oosterhuis, D.M. (1999). Foliar potassium fertilization of cotton. *In:* "Frontiers in Potassium Nutrition: New Perspectives on the Effects of Potassium on Physiology of Plants" (D.M. Oosterhuis and G.A. Berkowitz, eds.). pp. 87-99. Potash & Phosphate Institute, Atlanta, Georgia.

Potts, J.M. (1984): Fluid Fertilizers. Bulletin Y-185, TVA/OACD 84/7. Tennessee Valley Authority, Muscle Schoals, AL.

Rhoades, J.D. and Loveday, J. (1990): Salinity in irrigated agriculture. *In:* "Irrigation of Agricultural Crops" (B.A. Stewars and D.R., Nielsen, eds.). pp. 1089-1142. ASA/CSAA/SSSA, Madison, WI.

Rug, H. and Kahle, K. (1990): Tailoring Potash to the Needs of the Fertilizer Industry. The Fertiliser Society Proceedings 297. 40 pp. The Fertiliser Society, York, UK.

Scaife, A. and Bar-Yosef, B. (1995): Nutrient and Fertilizer Management in Field Grown Vegetables. IPI-Bulletin 13. International Potash Institute, Basel, Switzerland.

Sneh, M. (1995): The history of fertigation in Israel. *In:* "Proceedings Dahlia Greidinger International Symposium on Fertigation". pp. 1-10. Technion, Haifa, Israel.

Subramanian, K.S. (1994): Influence of soil and foliar application of potassium on growth, nutrient utilization, yield and quality of sugarcane (*Saccharum officinarum* L.). *New Botanist* **21**, 13-20.

Svensson, J.E.T. (1994): Fertiliser Spreading and Application. The Fertiliser Society Proceedings 357. 40 pp. The Fertiliser Society, York, UK.

Tarchitzky, J. and Magen, H. (1997): Potassium in soils and crops, recommendations and present use in Israel. *In:* "Food Security in the WANA Region, the Essential Need for Balanced Fertilization" (A.E. Johnston, ed.). International Potash Institute, Basel, Switzerland.

Umar, S., Bansal, S.K., Imas, P. and Magen, H. (1999): Effect of foliar fertilization of potassium on yield, quality and nutrient uptake of groundnut. *J. Plant Nutr*. **22**, 1785-1795.

Vyn, T., Janovieek, K. and Broulsema, T. (1999): Banded potash boosts no-till corn yield. *Better Crops* **83,** 8-9.

Welch, L.F., Johnson, P.E. and Mc Kibben, G.E., Boone, L.V. and Pendleton, J.W. (1966): Relative effectiveness of broadcast versus banded potassium for corn. *Agron. J.* **58,** 618-624.

Wolf, B., Fleming, J. and Batchelor, J. (1985): Fluid Fertilizer Manual. Vol. 1 and 2. National Fertilizer Solutions Association, Peoria, IL.

Xu, G.H., Shen, Q.R., Zhen, W.J., Tan, S.H., and Shi, R.H. (1999): Biological responses to foliar feeding of macroelement fertilizers during middle-later stages of wheat and corn. *Acta Pedologica Sinica* **36,** 454-462.

Xu, G.H. and Bao, S.D. (1995): The relationship between potassium absorption ability and root parameters of different crops. *J. Nanjing Agri. Univ.* (Chinese). **18,** 49-52.