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Effect of Potassium on the Production and Quality of Tobacco Leaves

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Tobacco plantation and barn in Cuba. Photo by M. Marchand.

Abstract

Potassium (K) and nitrogen (N) are two major nutrients in crop production. A deficiency of either one or both of these nutrients causes yield loss. In the specific case of tobacco production, both nutrients play a key role in controlling important quality parameters such as leaf colour, texture, hygroscopic properties, combustibility, sugar and alkaloid contents. Monitoring N applications thoroughly for form, quantity, and timing of application is a prerequisite in modern agriculture. As in other field crops, balanced N-K fertilization enhances tobacco growth and improves the uptake of both nutrients, which in turn reduces nitrate losses during and after the cropping season. The importance of K on mineral nutrition in tobacco production in terms of yield and quality is presented. The role of K in determining the chemical composition of tobacco leaf is now well established. K content of dry matter must reach 2 to 2.5 percent and chloride (Cl) content must remain below 1 to 1.5 percent in order to ensure good maturation, perfect combustibility and a good taste. The paper reports several pot and field experiments carried out in France, China and Cuba, in which various factors affecting yield and quality of the tobacco crop were studied including dose, source, and timing of potash applications. The effect of the combination of various potash forms (potassium sulphate, potassium chloride, potassium nitrate, potassium bicarbonate) with two N sources (nitrate –N from potassium nitrate, and ureic-nitrogen from urea) was investigated. The following measurements were recorded: yield parameters; mineral nutrients; sugar; the alkaloid contents of tobacco leaves at three stalk-levels; and water-soluble alkalinity which is an indicator of combustibility. In an experiment on tobacco for cigar production, the effect of sources of K for fertigation was investigated showing the benefit of potassium sulphate on quality of tobacco when applied over a longer period. Finally, an experiment with foliar applications of potassium sulphate in China is presented, illustrating the positive effect of foliar applied K on K content in the tobacco leaf.

Keywords: Tobacco, mineral nutrition, potassium, leaf composition, fertigation, foliar application.

Introduction

Growth and general physiology of crop plants can be significantly altered by varying cultural practices. In tobacco, the effects of spacing, topping, suckering, and harvesting all directly influence total yield as well as the proportion of the different classes of leaf, and their chemistry.

Standard tobacco production requires 130-150 kg N ha^{-1}, 30-40 kg P_2O_5 ha^{-1} and 230-240 kg K_2O ha^{-1} which is closely dependent on mineral nutrient supply. Fertilization also plays a key role in influencing the most important quality parameters such as leaf colour, texture, hygroscopic properties, combustibility, sugar and alkaloid contents. Leaf-burn, or combustibility, is one of the key criteria taken into account by the tobacco industry for assessing quality. Many studies have shown that organic acids, associated with K, enhance combustibility, whereas excessive N, especially in the ammonium form, is detrimental in this respect. The detrimental role of Cl in inducing leaf-burn and poor smoke taste is well documented in contrast to the role of other nutrients, such as sulphur (S), where their influence is less known. Sugar and alkaloid content are also important parameters of quality, which are partly controlled by mineral nutrition, and especially by the quantity and form of N fertilizer applied.

This paper presents the results of pot and field experiments carried out over recent years in France, Cuba and China to improve knowledge of the influence of

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fertilizer application on the yield and quality of the tobacco crop. The K fertilizer sources used in these experiments were potassium nitrate (KNO_3, NOP), potassium sulphate (K_2SO_4, SOP), potassium chloride (KCl, MOP) and potassium bicarbonate (K_2CO_3, Kbic).

Table 1. Soil analysis for the pot experiments (P_2O_5 Joret Hebert).

	Clay	Silt	Sand	pH	O.M.	CEC	P_2O_5	K_2O	K/CEC	MgO	CaO	Cl
	-----%-----				%	*meq 100 g⁻¹*	----*ppm*----		%	-----*ppm*-----		
Content	15.6	76.8	5.5	6.2	2.12	10.2	153	73	1.52	100	2.87	11

Table 2. Quantities of fertilizers applied on the pot experiments.

Fertilizer	Flue-cured		Air-cured	
	g pot⁻¹	*kg ha⁻¹*	*g pot⁻¹*	*kg ha⁻¹*
KNO_3	17.61	80N+270K20		
KNO_3+urea			25.98+5.06	200N+400K20
K_2SO_4+urea	14.82+4.98	80N+270K20	21.98+12.41	200N+400K20
KCl+urea	12.64+4.98	80N+270K20	18.74+12.41	200N+400K20
K_2CO_3+urea	11.34+4.98	80N+270K20	16.81+12.41	200N+400K20

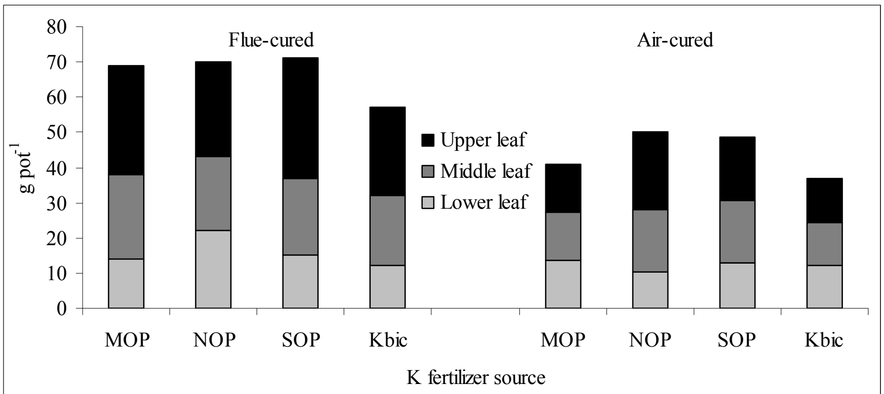

Fig. 1. Dry matter production of flue-cured and air-cured tobacco leaves with different sources of K fertilizers.

France - pot experiments (1995)

Two experiments were carried out in which the pots were irrigated daily, with leached water being recycled for the next irrigation. The first experiment was conducted on dark air-cured tobacco (ITB 1000) from December 1994 till May 1995 in a closed greenhouse under controlled conditions, and the second on flue-cured tobacco (ITB 32) grown from June till September 1995 in an open greenhouse with adjustable roof protection.

Soil analysis

The same soil was used for both experiments: a loamy soil, slightly acidic, poor in phosphorus, and very poor in exchangeable K (Table 1). All fertilizers were mixed with the soil before filling the pots.

Treatments

The quantity of K applied to Virginia flue-cured tobacco was fixed at 270 kg K_2O ha^{-1}, corresponding to the concentration of NOP (13-0-44) on the basis of 80 kg of N, in accordance with K and N requirements under French conditions (Table 2). NOP, SOP, KCl and Kbic were applied with urea on the same basis for N and K quantities. Dark air-cured tobacco grown under French conditions requires 200 kg ha^{-1} and 400 kg K_2O ha^{-1} on the basis of 38,000 plants ha^{-1}. In this case, the additional N required in the NOP treatment was made up with urea in order to have the same rate of N application in all treatments (Table 2). Each treatment was replicated six times and randomised within each block. The equivalent of 75 kg P_2O_5 ha^{-1} and 20 kg MgO ha^{-1} was applied uniformly as triple super phosphate and as magnesium carbonate.

Results

Dry matter production

SOP, MOP, and NOP appeared to be equivalent in terms of total yield production whereas Kbic gave the lowest yields in both experiments (Fig. 1). The relevant quantity of dry matter (DM) produced was much higher for flue-cured tobacco, probably because the air-cured experiment was made under completely artificial conditions for light and temperature.

Mineral composition

Nitrogen

As expected, the total N content was higher for air-cured tobacco, receiving the equivalent of 200 kg N ha^{-1} in comparison to the flue-cured tobacco which received only 80 kg N ha^{-1}. For both, more than 95 percent of the total N was in organic form (see Fig. 2). The nitrate content was highest with the NOP treatment in the flue-cured experiment, but this was not the case for the air-cured (results not shown).

Potassium

The threshold of two percent necessary for adequate quality of tobacco was easily achieved in both experiments

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(Fig. 3). It is worth remembering, however, that this value is not so easily reached under field conditions. All potash forms gave similar results in terms of K concentration in tobacco leaves. The K content decreased from lower to upper leaves, which is in agreement with previous observations. Although the air-cured tobacco received a much higher application of potash (400 kg K_2O ha^{-1}) than the flue-cured tobacco (270 kg K_2O ha^{-1}) as occurs in practice in contrast to N, the leaves of the air-cured did not contain more K except in the upper leaves.

Sulphur

The S concentration remained below the 0.65 percent threshold. Even with the equivalent of 800 kg ha^{-1} of SOP (144 kg S ha^{-1}), the maximum concentration reached was 0.49 percent. This finding confirms previous results that S uptake seem to be self-regulating in tobacco. Despite high application of sulphate, the resulting S concentrations in the leaves did not exceed 0.5 percent. This value is very low in comparison to Cl fertilization in which leaf Cl concentrations can reach up to about four to nine times that level (Fig. 5).

Chloride

In both experiments the Cl content was very high in the MOP treatment. It is generally accepted in the tobacco industry that a very good grade of tobacco requires less than one percent Cl and when it exceeds two percent Cl, the tobacco has no commercial value.

Water-soluble alkalinity

There is a highly significant relationship between leaf-burn and water-soluble ash alkalinity (WSA). An even closer relationship is obtained if WSA is replaced by the ratio of WSA to total N, expressed as percent of the DM. Potentially, the higher this ratio, the better the combustibility. In both experiments, the lowest ratios, and consequently the lowest potential regarding combustibility, were obtained in the MOP treatment which relates to the high Cl content. WSA values were similar for NOP, SOP, and Kbic treatments in both experiments. Highest WSA:N ratios were found for Kbic in the flue-cured experiment because the total N content was lowest in this treatment. The ratios for NOP and SOP were similar. Consequently, S content

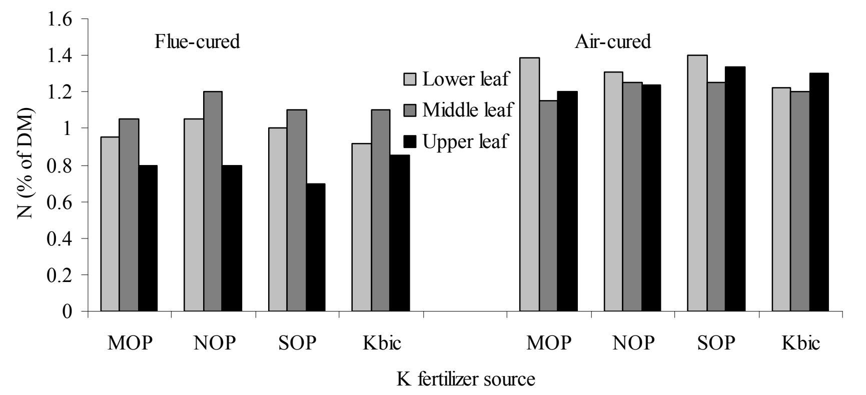

Fig. 2. N concentration (percent in DM) in flue-cured and air-cured tobacco leaves with different sources of K fertilizers.

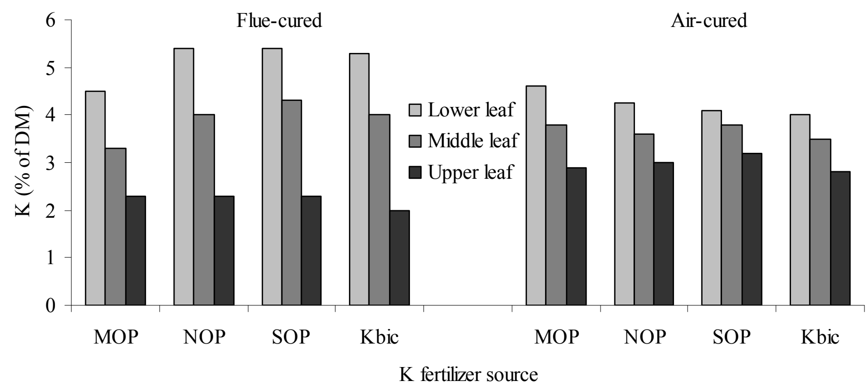

Fig. 3. K concentration (percent in DM) in flue-cured and air-cured tobacco leaves with different forms of K fertilizers.

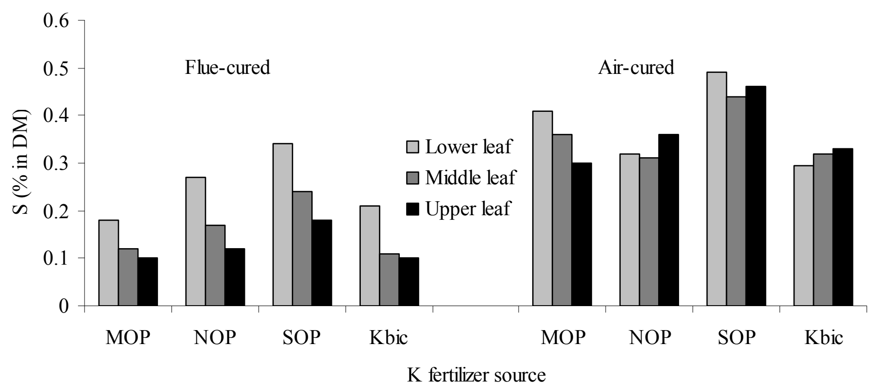

Fig. 4. Sulphur concentration (percent in DM) in flue-cured and air-cured tobacco leaves with different forms of K fertilizers.

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has probably only a marginal effect on combustibility compared to K and Cl.

France - field experiments (2001)

Materials and methods

An experiment was carried out in 2001 at Pôle d'Aspach, a research station in the eastern part of France. This station is located in the second largest tobacco cropping area in the country and the aim of the experiment was once again to examine the effect of N and K application in relation to timing. The three treatments maintained the same nutritional levels as 156 kg ha^{-1} N, 100 kg ha^{-1} P_2O_5, and 400 kg ha^{-1} K_2O. The fertilizers applied were ammonium nitrate (AN), NOP, SOP and a soluble form of K sulphate:

T1: conventional fertilization at planting (AN + SOP, 466 + 800 kg ha^{-1}), using drippers for irrigation only (control).

T2: conventional fertilization at planting (AN + SOP, 299 + 400 kg ha^{-1}) and fertigation every week with AN + soluble SOP (56 + 40 kg ha^{-1}) for three weeks followed by fertigation with soluble SOP (40 kg ha^{-1}) for seven weeks.

T3: conventional fertilization at planting (AN + SOP, 299 + 400 kg ha^{-1}) and fertigation every week with NOP (43.5 kg ha^{-1}) for ten weeks.

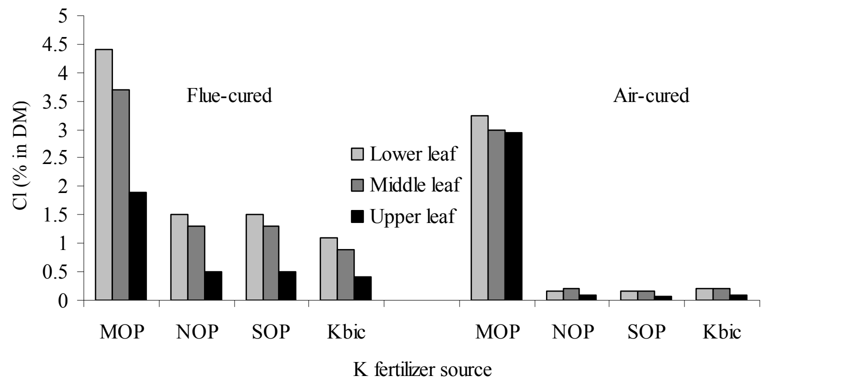

Fig. 5. Chloride concentration (percent in DM) in flue-cured and air-cured tobacco leaves with different forms of K fertilizers.

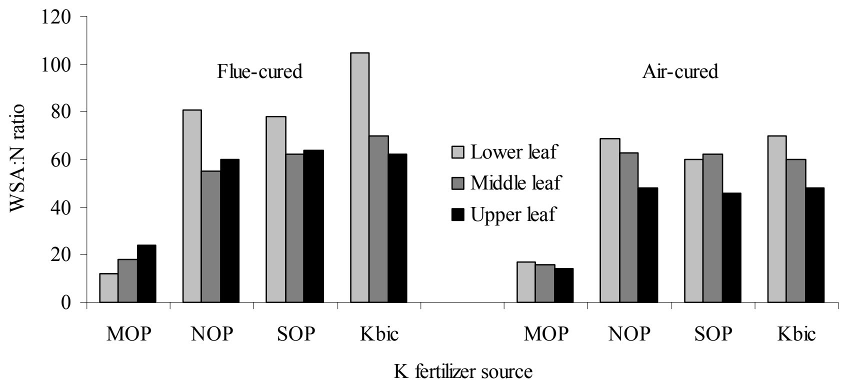

Fig. 6. WSA:N in DM ratio in flue-cured and air-cured tobacco leaves with different forms of K fertilizers.

Results

In the two field experiments, both leaf production and quality parameters (based on tobacco industry criteria) were analyzed. Table 3 reports leaf production and shows the advantage of an early N application followed by a later application of K in response to plant requirement. Table 4 indicates that quality is also in line with yield production. Treatment 2 gave the lowest N and Cl contents, and adequate K based on cigarette factory requirements. In addition, S values did not exceed the threshold of 0.65 percent (considered as the maximum for a good combustibility).

For both varieties, the grade index shows there is a benefit from the application of N in the first three weeks after planting (Table 5). On Virginia, the effect was much more pronounced and the fraction of class A leaf was close to 60 percent.

Table 3. Influence of the treatments on tobacco yield.

Treatment	Black tobacco		Virginia tobacco	
	------------*g ha*$^{-1}$------------			
T1	14,396	b	9,587	c
T2	15,650	a	11,637	a
T3	14,743	b	10,309	b
SE	890 kg		444 kg	
CV %	6.00		4.40	

Table 4. Mineral composition of the leaves (%).

Treatment	Black tobacco				Virginia tobacco			
	N	K	Cl	S	N	K	Cl	S
	--%--							
T1	2.09	3.21 a	0.38 b	0.56 b	1.08 a	2.26 a	0.12 a	0.43 a
T2	2.06	3.09 b	0.35 c	0.60 a	1.04 b	2.23 b	0.10 b	0.44 a
T3	2.08	2.88 c	0.47 a	0.51 c	1.08 a	2.17 c	0.13 a	0.34 b
SE	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.04
CV %	1.2	0.6	2.6	0.3	0.8	0.6	4.4	0.8

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Table 5. Grade index for black and Virginia tobacco (%); grades: from A, high quality to E, low quality (classification used by European tobacco industry).

Treatment	Black tobacco					Virginia tobacco				
	A	B	C	D	E	A	B	C	D	E
T1	17	36	0	0	47	22	2	6	0	71
T2	21	20	11	0	47	59	4	12	0	26
T3	21	14	13	0	52	36	11	15	0	38

Cuba - field experiments (1997/2001)

In order to define the most suitable timing and number of applications of fertilizer on shade-grown, dark tobacco (variety "Criollo 98") for cigar production, fertigation research was carried out at the Tobacco Experimental Station in San Juan y Martinez, Pinar del Río province where five treatments were studied.

Table 6. Treatments for the Cuban experiment.

Treatment	Type	K fertilizer	Method	N; K fertigation
T1	Farmer's practice	SOP	Manure + fertigation	0 to 18 DAT
T2	Recommended program, based on absorption curves	SOP	Basal dressing + fertigation	N fertigation from 0 to 21 DAT; K fertigation from 0 to 28 DAT
T3	Standard program	SOP	Fertigation only	N and K fertigation from 0 to 21 DAT
T4	Program based on NOP	NOP	Basal dressing + fertigation	N and K fertigation from 0 to 28 DAT
T5	T5 = T2 without basal dressing	SOP	Fertigation only	N fertigation from 0 to 21 DAT; K fertigation from 0 to 28 DAT

DAT – days after transplanting.

Table 7. Soil analysis before and after the experiment.

Treatment	pH	Organic matter	Concentration in soil	
			K_2O	P_2O_5
		%	*------mg 100 g^{-1}------*	
Before	6.02	2.59	15.79	46.50
After (T1)	6.10	2.44	14.41	39.26
After (T2)	5.90	2.54	15.45	37.87
After (T3)	6.05	2.49	15.63	43.62
After (T4)	6.00	2.42	15.57	44.75
After (T5)	6.12	2.50	15.23	45.38

Materials and methods

The soil at this station was classified as an Ultisol, with ferrallitic quartzitic yellow and lixiviated characteristics according to the latest classification of Soil Taxonomy. The experiment was conducted following a protocol using long plots with five treatments and four replications.

The fertilizers applied were ammonium nitrate (AN), NOP and a soluble form of potassium sulphate. The five different treatments of the experiment are described in Table 6. For all treatments, levels of N, P_2O_5, and K_2O were 125, 51 and 188 kg ha^{-1} respectively, but applied at different times and methods. The variety used was "Criollo 98" developed at the Tobacco Experimental Station. For this variety the size of the largest leaf ranges between 33 and 36 cm in maximum width and between 53 and 58 cm in length. The variety has a potential mean yield of 2,250 kg ha^{-1}, and is resistant to the main diseases. Five plants were selected and identified at random in the calculation area in each plot between 20 and 25 days after the plantation establishment. Measurements of the length, width and dry mass of the middle leaf were made according to Torrecilla *et al.* (1980). Combustibility was measured by the procedure proposed by Guardiola (1992). In the cultivation of the crop, all normal agricultural procedures were carried out as required in wrapper tobacco production. The crop was planted during the second ten days of November and harvested at the beginning of February.

Results and discussion

The mean temperature, relative humidity and precipitation during the three-year experiment did not show any significant difference to the mean value over 25 years for any of the months in which the field experiments were carried out.

In the soil tests for each experimental plot, conducted before and after concluding each season, only small variations in the values of pH, OM, and P and K concentrations were observed (Table 7).

It should be noted that the nutrient ratios K/Ca, Ca/Mg, and pH were based on the recommendations in Cuba according to Morejón (1988).

Table 8 indicates that in all treatments, the increase in length, width, dry mass, and combustibility of the leaf were superior to the control (farmers' practice). Combustibility was considered "excellent" in all treatments but the control. The combination of formulations used in T2 (basal dose + NK fertigation, using SOP and limiting N application to 21 DAT) achieved the highest dry matter yield, while that of T4 (basal dose + NK fertigation, using NOP and NK fertigation till 28 DAT) achieved the highest combustibility value.

Table 9 presents the yield and its fractions. Highest yield of wrapper leaves for export, a very significant factor for the economics of tobacco growing, was achieved with T2. This

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treatment was superior in all fractions, demonstrating the value of SOP used with shortened time for N fertigation to reduce its negative effects (up to 21 DAT), and long for K fertigation (up to 28 DAT).

In general, under these Cuban conditions, fertigation between 7 and 28 days after transplanting with four application timings, markedly increased the quality and total yield of cigar wrappers for export.

As a consequence of the results obtained in the experiment, the recommendation to tobacco growers is to use fertigation techniques and to limit N application to the first stage of the vegetative cycle, whilst taking advantage of the fact that K can be successfully applied later.

Table 8. Influence of the treatments in the biological indices.

Treatment	Length		Width		Dry matter		Combustibility [*]
	------------*cm*----------				*g*		*seconds*
T1	46.75	c	27.5	b	3.90	c	18.50
T2	59.75	a	33.2	a	4.85	a	24.25
T3	48.50	bc	26.2	b	4.11	b	22.50
T4	48.00	bc	27.0	b	3.18	d	28.50
T5	51.50	b	28.0	b	3.87	c	26.25
SE	1.13		0.77		0.27		-
CV %	4.59		5.64		2.95		-

[*] According to Guardiola (1992), combustibility is considered low (0-5 sec.); acceptable (6-10 sec.); good (11-20 sec.) and excellent (>20 sec.).

Table 9. Influence of the treatments on yield and quality of production.

Treatment	Wrapper for export		Wrapper for national consumption		Binder and filler		Total yield	
	----------------------------------*kg ha*$^{-1}$----------------------------------							
T1	674.05	b	395.87	bc	621.32	d	1,691.24	d
T2	898.69	a	507.87	a	833.67	b	2,237.23	a
T3	661.62	b	343.17	c	764.87	c	1,769.66	c
T4	443.95	c	449.15	ab	913.25	a	1,806.35	bc
T5	499.20	c	443.77	b	873.94	ab	1,816.91	b
SE	20.18		20.06		15.80		14.55	
CV %	7.00		10.28		3.96		1.65	

China - field experiments (1997)

Materials and methods

As already observed on many crops, foliar application of soluble SOP has a positive effect on production and increases the K content of the leaf. Additionally, because of the lack of foliar-applied N, leaf N content decreases which is favourable for tobacco maturation.

Experiments were conducted in China and France. In the experiment presented below, carried out in Guangdong province, the same basal dressing was applied to each plot (120 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 200 kg K_2O ha^{-1}). Three foliar sprays were applied 45, 55 and 65 days after transplanting. Treatments were designed to determine the optimal K concentration in the foliar spray (Table 10).

Table 10. Effect of foliar application on tobacco leaf. Data from Hong He Tobacco Research Station.

Treatment	K content in leaf	Total yield	Upper leaves	Middle leaves
	%	----------*kg ha*$^{-1}$--------		
Control	1.66	2,709	1,524	838
Soluble SOP 2%	2.04	2,795	1,595	840
Soluble SOP 4%	2.17	3,062	1,628	970
Soluble SOP 6%	2.25	2,894	1,610	929

Results

The results confirmed that increased K concentration in the foliar spray solution up to six percent affects and increases K concentration in the leaves, which in turn increase yields. Maximum yield (3,062 kg ha^{-1}) was achieved with four percent of soluble SOP in the foliar spray. Foliar spray with six percent soluble SOP further increased K concentration in the leaves (2.25 percent), but with no further yield response. Foliar spray with four percent of soluble SOP achieved the highest tobacco quality (data not shown).

A high response was observed as the K content increased from 1.66 percent up to 2.25 percent as a consequence of increasing K content in the foliar spray. In comparison with the control, a slight effect on yield in upper and middle leaves was also observed. In relation to the foliar application, the small amount of sulphate of potash sprayed cannot in itself explain the K increase in the tobacco leaves. A tentative explanation to account for this beneficial effect may be as follows: spraying K salts on the leaves of plants of low K status but

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adequately supplied with other nutrients would be expected to promote sucrose (and K) transport in the phloem from shoot to roots. Energy would thus be provided to further root growth thereby enhancing K acquisition from the soil in a K pump-like action. Both foliar applied and any enhanced K uptake would also favour growth by improving water status, photosynthetic activity, protein synthesis etc.

Conclusions

From this series of experiments in different regions, and the experimental conditions under which they were carried out, the following conclusions may be drawn:

- K fertilization is a prerequisite to quality production of tobacco in order to improve curing and combustibility.
- Application of K fertilizers separately from N application can be beneficial because it allows the adjustment of N and K, both in supply and timing of supply, which in many cases can improve quality aspects of tobacco.
- MOP significantly reduces the quality of tobacco, which includes altering N metabolism and drastically decreasing combustibility.
- As a general rule, split applications of potassium are more efficient when water is not a limiting factor as shown in the experiments in France. In drip irrigation cropping systems, SOP and Kbic can be applied when K uptake is maximised and N is not required. NOP should be used only if application of N is limited at the early stage of tobacco growth, as demonstrated in the experiment from Cuba.

  Foliar application of K is a very effective way of supplying K under severe K deficiency or when K is restricted by soil characteristics. It enhances K uptake by the roots and consequently improves K leaf content which is an important quality criteria for the cigarette factories.

Drip irrigated tobacco experiment in France. Photo by M. Marchand.

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Regional Activities/WANA

Area and productivity of tobacco, 1980-2008

Total world production of tobacco in 2008 was 6.7 million mt, of which 2.8 million mt were produced in China, followed by Brazil (0.8), India (0.5) and the USA (0.36 million mt). While global area decreased from 5.3 million ha in the 90s to 3.8 million ha in 2008, productivity improved steadily and reaches now 1,770 kg ha^{-1} (unmanufactured). Data from FAOSTAT, accessed September 2010.