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Yield and Chemical Composition of Tobacco Leaves of Different Cultivars as Affected by Four Levels of Potassium Chloride

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Abstract. An outdoor pot experiment was conducted to evaluate response of ten tobacco (*Nicotiana tabacum*) cultivars to KCl induced chloride toxicity at the Tobacco Research Station, Mardan, Pakistan, during 2002. The study included four levels of KCl, which were: 0, 4, 8 and 12 mmol kg^{-1} soil and was arranged according to 4x10 factorial design with three replications. Seedlings of the respective cultivars, Spt-G.28, KHG-14, KHG-15, KHG-18, Coker-371 Gold, Candel, KHG-19, K-399, Coker-48 and Coker-176 were planted in pots containing 5 kg normal soil. After establishment of the seedlings, the respective amount of KCl was applied in one litre of water and then irrigated with normal water for the rest of the growing period. The data showed that all growth parameters increased with the initial dose of 4 mmol kg^{-1} of KCl, but then decreased with higher levels due to chloride toxicity. When averaged across cultivars, the highest seedling height (17.4 cm), number of leaves per plant (8.7), leaf area (42.0 cm^2), and dry weight (10.17 g per pot) were recorded in treatments receiving 4 mmol KCl kg^{-1} soil. Chloride, reducing sugars, nicotine and K content of leaves showed linear regression with KCl levels ($r^2 > 0.95$), producing 250, 74.33, 18.62 and 14.14% increase at 12 mmol kg^{-1} soil, respectively, as compared to control. Nitrogen content of leaves also increased with increasing KCl levels in most of the cultivars showing an overall increase of 12.46%, as compared to control. Unlike other growth parameters, ash content increased with increase in KCl level up to the higher dose of 12 mmol kg^{-1} soil. Cultivars showed differential response to the KCl induced chloride toxicity. KHG-14 was found to be the most sensitive cultivar regarding growth parameters, while KHG-18 and KHG-15 recorded higher changes in chemical composition to KCl application. Considering the overall performance, Spt-G.28 was found to be the most suitable variety producing higher plant height, number of leaves per plant, leaf area, fresh and dry weight, reducing sugars and nicotine, and lower levels of nitrogen and chloride as compared to other cultivars. It is concluded that KCl applications should be avoided or applied very carefully to prevent its adverse effects on yield and quality of tobacco as our soils already contain sufficient amount of chlorides.

Keywords: tobacco leaves, potassium chloride, *Nicotiana tabacum*, chloride toxicity, tobacco cultivation, phytotoxicity, tobacco cultivars, flue-cured cultivars

Introduction

The positive effects of potassium on tobacco and other agronomic crops have been reported by many researchers across the world. It is not only essential for normal physiological functions of the crop but also exerts a profound influence on the burning quality of tobacco leaf. It activates synthesis of proteins and various enzymes. Elliot and Vickery (1959) reported that potassium improves leaf quality and appears to aid in the synthesis of sugars and starch in the leaf. Ahmed *et al*. (1989), and Marwat and Gul (1992) found that potassium increased the average height of plants, number of leaves per plant, leaf area, and yield. They also reported substantial increase in the amount of reducing sugars and reduction in nicotine, nitrogen and chloride concentration with the application of potassium.

Like potassium, chloride is also involved in many biochemical processes (Karaivazoglou *et al.,* 2005). It is absorbed by plants as chloride ion, through both roots and aerial parts. The essential role of chloride seems to lie in its biochemical balance, which enables it to participate in osmotic and cation neutralization. A useful function of chloride is counter-ioning during rapid potassium fluxes, thus contributing to turgor of leaves and other plant parts. A number of studies have shown a positive correlation between the concentration of chlorides and sugars in the leaves (Hawks and Collins, 1983; Sierra 1966; Peele *et al.,* 1960; Woltz *et al.,* 1948). Chloride also appears to have a definite role in the evolution of oxygen in photosystem-II during photosynthesis (Kelley and Izawa, 1978). Jaifu (1999) reported that addition of chloride as KCl improved the growth of flue-cured tobacco by 2.6 to 18.5% with the application of 30 to 98 kg chloride per hectare, when the soil chloride was below 20 mg kg^{-1} soil. Tobacco plant nitrogen, potassium and chloride contents of leaf, and the external and internal quality characteristics of the tobacco leaf have been also reported to increase with the higher application of KCl. Zhang *et al.* (1999) reported that leaf chloride contents were 8-24%

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higher in plants given 5.0 g chloride per plant, as compared with controls (no chloride applied) and with those given up to 3.0 mg chloride per plant. Plant dry weight also increased with the chloride application rate up to 3.0 g chloride per plant, which decreased later on.

Above a certain threshold level, chloride becomes toxic (American Tobacco Company, 1958), and has been reported to be associated with certain abnormal growth features and undesirable properties in the cured leaves. If the phytotoxicity develops early in the growing season, the plants become stunted. Cured tobacco leaves with high chloride content tend to be soggy in nature and dull in colour, turning dark on ageing, have a low fire holding capacity, and are poor in flavour and quality (Akehurst, 1968; Peele *et al.*, 1960; Flower, 1999).

Crops and plants do not respond to salts in a similar manner (Maas, 1986; Maas and Hoffman, 1977). Salt sensitive varieties accumulate excessive amounts of chloride, which are toxic to plants. Tobacco is generally susceptible to chloride toxicity, however, tolerance varies among the varieties. The differences reflect the plant capability to prevent or retard chloride accumulation, while in some cases the same amount may cause injury and death to the plants.

Nowadays, high chloride concentration in the soil and irrigation water is generating concern in almost all tobacco growing areas of Peshawar valley, Pakistan. This study was planned to investigate the beneficial effects of KCl while monitoring chloride toxicity, and to evaluate response of ten tobacco cultivars to the KCl induced chloride salinity. The ultimate goal was to help in increasing the production and improving the quality of tobacco.

Materials and Methods

A composite surface soil sample (0-15 cm) was collected from the field at Tobacco Research Station, Mardan, Pakistan. The bulk sample of soil was mixed thoroughly and analyzed for various physicochemical characteristics. The soil was silt-loam with a the pH of 7.6 and EC of 0.40 dSm^{-1}, deficient in nitrogen (0.07%), marginal in phosphorus (10.8 mg kg^{-1}) and potassium (115 mg kg^{-1}), and having chloride content of 50 mg kg^{-1} soil.

The study included ten cultivars and four levels of KCl applications, replicated three times. The salt levels included KCl per litre solution, 0, 20, 40 and 60 mmol, added to pots containing 5 kg of soil. As such, KCl treatments were equivalent to 0, 4, 8 and 12 m mol KCl kg^{-1} soil. Seedlings of ten flue-cured virginia (FCV) tobacco cultivars, namely, Spt-G.28, KHG-14, KHG-15, KHG-18, Coker-371 Gold, Candel, KHG-19, K-399, Coker-48 and Coker-176, were transplanted in pots on March 4, 2002. After establishment of the seedlings, the respective amounts of KCl were applied on March 11, 2002 and then irrigated with distilled water for rest of the growing period. The agronomic data on plant height, number of leaves per plant, and leaf area were recorded before the plants were harvested on May 16, 2002. Fresh weight of leaves was recorded immediately after harvesting while dry weight was recorded after 15 days of air drying at room temperature.

The leaves were ground and analyzed for chemical characteristics on moisture-free basis after acid digestion (Walsh and Beaton, 1973). Nitrogen was determined following the method of Bremner and Mulvaney (1982), and potassium was determined by flame photometric method (Thomas, 1982). Reducing sugars were estimated in accordance with the method of Lane and Eynon as described by Pearson (1962), and chloride was determined by the method of Chapman and Pratt (1961). Nicotine was determined by the method of Cundiff and Markunas (1964). Statistical analyses were performed as suggested by Steel and Torrie (1980) and the treatment means were compared with least significant difference test.

Results and Discussion

Summary of analysis of variance (ANOVA) is given in Table 1, showing significant effect of KCl and differences in the response of cultivars in respect of all the parameters studied. Interactions between cultivars and KCl were significant at all parameters, except seedling height, number of leaves per plant, leaf area and leaf potassium concentration. The effect of KCl

Table 1. Summary of analysis of variance (ANOVA), showing the effects of KCl application on various parameters of different tobacco cultivars (F values)

Parameters analyzed	Source of variations		
	varieties	KCl	varieties x KCl
Seedling height (cm)	12.61***	36.03***	1.81
Number of leaves ($plant^{-1}$)	4.14**	21.98***	1.21
Leaf area (cm^2)	10.93***	87.04***	1.90
Fresh weight (g)	157.33***	315.50***	22.64***
Dry weight (g)	558.77***	1007.31***	58.62***
Ash (%)	3.58*	10.81**	4.98***
Reducing sugars (%)	25.39***	518.45***	3.83*
Nicotine (%)	66.98***	178.40***	5.07***
Chloride (%)	14.81***	1009.21***	3.51*
Nitrogen (%)	88.12***	47.91***	3.51*
Potassium (%)	5.87***	80.32***	1.95

*significant at $p < 0.05$; **significant at $p < 0.01$; ***significant at $p < 0.001$

concentration on these parameters and differential responses of different cultivars are discussed in detail in the succeeding sections.

Agronomic characteristics as influenced by KCl. Seedling height, number of leaves per plant, leaf area, fresh and dry weight, and ash content were significantly affected by KCl application ($P < 0.05$) and different cultivars responded differently (Table 2). The plant height significantly increased at 4 mmol KCl kg^{-1} soil in all the cultivars studied as compared to control. But applications beyond 4 mmol KCl kg^{-1} soil depressed the plant growth. When averaged across cultivars, the highest plant height of 17.4 cm was recorded at 4 mmol KCl kg^{-1} soil. Application of KCl at 12 mmol KCl kg^{-1} soil produced the shortest plants with mean value of 12.5 cm, thereby decreasing plant height by 15.16%. Cultivars varied in response to KCl concentration, KHG-14 being the most sensitive showing about 30% reduction in plant height at 12 mmol KCl kg^{-1} soil, whereas cultivars Candel and KHG-15 were the most resistant cultivars as compared to control. Variations in the height of cultivars as compared with control suggested physiological characteristics (Table 2).

Like plant height, initially the number of leaves increased with KCl application at 4 mmol KCl kg^{-1} soil, with the maximum number of leaves of 8.7, but higher concentrations reduced the number of leaves per plant to 6.4 at 12 mmol KCl kg^{-1} soil. Cultivar KHG-14 was found to be the most sensitive with 27.97% reduction in the number of leaves per plant, while Candel and KHG-15 were the most tolerant (Table 3).

Mean cultivar leaf area was also higher at 4 mmol KCl kg^{-1} soil, which reduced as the concentration increased, producing the minimum at 12 mmol KCl kg^{-1} soil with 6.25% reduction as compared to control. Cultivars showed differential response to KCl concentration. For instance, cultivars Spt-G.28, KHG-19 and K-399 showed 45.9, 64.7 and 74.3% increase, respectively, at 4 mmol kg^{-1} soil, while KHG-14 showed increase of only 16.0% in leaf area, suggesting substantial differences in these cultivars to KCl concentrations (Table 4). Similar varietal difference can be noticed in reduction of leaf area at the highest concentration, whereby KHG-14 showed maximum reduction of 24.53%, and Spt.28, KHG-19 and K-399 being closer to control (Table 4).

Fresh yield of tobacco seedlings tended to increase with KCl applications up to a certain level, i.e., 4.0 or 8.0 mmol kg^{-1} soil, and then reduced with further increment depending upon the cultivar. The mean highest yield of all cultivars of 66.6 g per pot was recorded in treatments receiving 8 mmol KCl kg^{-1} soil. Cultivars Spt-G.28, K-399 and KHG-18 showed 83.0, 80.5 and 50.1% increase, respectively, at 4 mmol KCl kg^{-1} soil, while remaining cultivars with the exception of KHG-14, showed increase up to 8 mmol KCl kg^{-1} soil (Table 5).

Dry matter yield (air dried) also showed substantial increase with lower doses of KCl applications, but decreased with increasing level of KCl application in a differential manner with respect to varietal response. The highest yield of 10.17 g per pot was recorded in the treatments receiving 4 mmol

Table 2. Seedling height (cm) of different tobacco cultivars as influenced by different levels of KCl applications in a pot experiment

Varieties	KCl (mmol kg^{-1} soil)				Mean	Reduction in respect to control (%)
	0	4	8	12		
Spt-G.28	18.3	22.0	23.3	15.3	19.7^{a}	16.37
KHG-14	17.3	17.7	13.7	12.0	15.2^{b}	30.76
KHG-15	13.7	15.0	14.7	13.0	14.1^{bcd}	4.90
KHG-18	12.0	15.3	12.7	11.0	12.8^{d}	8.33
Coker-371Gold	15.7	19.3	14.0	12.0	15.3^{b}	23.42
Candel	12.7	18.3	17.7	13.0	15.4^{b}	-
KHG-19	13.3	15.3	13.3	12.0	13.5^{cd}	9.98
K-399	14.0	17.0	16.0	11.7	14.7^{bc}	16.64
Coker-48	14.7	16.0	13.7	12.0	14.1^{bcd}	18.20
Coker-176	15.7	18.0	14.0	13.0	15.2^{b}	17.04
Mean	14.7^{b}	17.4^{a}	15.3^{b}	12.5^{c}		15.16

least significant difference (LSD) for KCl effect at $p < 0.05 = 0.944$; LSD for varietal effect at $p < 0.05 = 1.492$

Table 3. Number of leaves per plant of different cultivars as influenced by different levels of KCl applications in a pot experiment

Varieties	KCl (mmol kg^{-1} soil)				Mean	Reduction in respect to control (%)
	0	4	8	12		
Spt-G.28	8.0	9.3	10.3	7.3	8.7^{a}	8.38
KHG-14	8.3	8.7	7.0	6.0	7.5^{bc}	27.97
KHG-15	6.0	8.0	7.3	6.3	6.9^{cd}	-
KHG-18	6.0	8.0	6.0	5.0	6.3^{d}	16.67
Coker-371Gold	8.0	9.3	7.7	6.0	7.8^{bc}	25.00
Candel	6.0	9.7	9.0	7.0	7.9^{ab}	-
KHG-19	6.7	8.0	7.0	6.0	6.9^{cd}	10.04
K-399	7.3	8.7	8.3	6.0	7.6^{bc}	18.14
Coker-48	7.3	8.7	6.3	7.0	7.3^{bc}	4.50
Coker-176	8.0	9.0	7.0	7.0	7.8^{bc}	12.50
Mean	7.2^{b}	8.7^{a}	7.6^{b}	6.4^{c}		11.16

least significant difference (LSD) for KCl effect at $p < 0.05 = 0.593$; LSD for varietal effect at $p < 0.05 = 0.937$

KCl kg^{-1} soil. Spt-G.28 recorded the highest response, showing an increase from 9.79 to 16.73 g per pot at 4 mmol KCl kg^{-1} soil, whereas the lowest response was recorded in KHG-14 (Table 6). The observed increases in plant height, number of leaves per plant, leaf area, fresh and dry weight, and ash content with 4 mmol KCl kg^{-1} soil can be attributed to the beneficial effect of potassium (Marwat and Gul, 1992), and decreases in these agronomic parameters at the higher levels of KCl could be due to the adverse effect of chloride (Karaivazoglou *et al.,* 2005; Flower, 1999; Akehurst, 1968; Peele *et al.,* 1960). The variation in responses of cultivars to the KCl induced chloride toxicity is in line with the findings reported earlier (Maas, 1986; Maas and Hoffman; 1977).

Ash content increased with increasing KCl concentrations. The mean highest ash weight of 12.74 g per pot was recorded in treatments receiving the highest dose of KCl (12 mmol KCl kg^{-1} soil), while the lowest was recorded in control treatment (Table 7).

Chemical composition of tobacco leaves as influenced by KCl. The effect on the chemical composition, as related with applications of different levels of KCl, was determined in respect of the constitutents of reducing sugars, nicotine, nitrogen and potassium.

Reducing sugars. Unlike plant growth, reducing sugars increased significantly (%) with the application of KCl for all cultivars (Table 8). However, different cultivars responded differently. When averaged across cultivars, the mean of reducing sugars (%) increased linearly ($r^2 = 0.9761$; Fig. 1a) from 4.92 to 8.58 with 74.33% increase as compared to control. KHG-15 and KHG-18 showed almost 100% increase in the amount of reducing sugars in treatments receiving KCl at 12 mmol KCl kg^{-1} soil as compared to control. The lowest response was recorded in Coker-371 Gold, showing 51% increase in reducing sugars as compared to control. When

Table 4. Leaf area (cm) of seedlings of different tobacco cultivars as influenced by different levels of KCl applications in a pot experiment

Varieties	KCl (mmol kg^{-1} soil)				Mean	Reduction in respect to control (%)
	0	4	8	12		
Spt-G.28	34.4	50.2	47.0	38.6	42.6^{a}	-
KHG-14	31.8	36.9	32.7	24.0	31.4^{de}	24.53
KHG-15	23.4	36.0	37.2	22.8	29.9^{e}	2.56
KHG-18	26.5	37.0	39.9	25.0	32.1^{cde}	5.74
Coker-371Gold	29.0	37.0	31.7	24.0	30.4^{e}	17.24
Candel	22.5	39.2	34.2	19.2	28.8^{e}	14.74
KHG-19	27.8	45.8	33.3	30.0	34.2^{bcd}	-
K-399	25.7	44.8	50.0	26.1	36.6^{b}	-
Coker-48	31.1	47.8	42.0	28.8	37.4^{b}	7.25
Coker-176	32.1	45.6	37.8	27.0	35.6^{bc}	15.84
Mean	28.4^{c}	42.0^{a}	38.6^{b}	26.5^{c}		6.59

least significant difference (LSD) for KCl effect at $p < 0.05 = 2.286$; LSD for varietal effect at $p < 0.05 = 3.615$

Table 5. Fresh weight (g) of seedlings of different tobacco cultivars as influenced by different levels of KCl applications in a pot experiment

Varieties	KCl (mmol kg^{-1} soil)				Mean
	0	4	8	12	
Spt-G.28	54.95	100.54	89.11	80.01	81.2^{a}
KHG-14	50.05	53.93	56.24	54.4	53.7^{d}
KHG-15	30.5	39.13	53.59	34.4	39.4^{g}
KHG-18	37.33	56.03	47.96	37.64	44.7^{f}
Coker-371 Gold	44.4	47.3	59.63	50.4	50.4^{e}
Candel	42.05	66.5	75.87	53.07	59.4^{b}
KHG-19	51.15	51.75	67.92	52.64	55.9^{cd}
K-399	36.75	66.36	52.26	47.94	50.8^{e}
Coker-48	44	63.24	79.15	50.01	59.1^{b}
Coker-176	45.13	47.92	84.7	49.4	56.8^{bc}
Mean	43.6^{d}	59.3^{b}	66.6^{a}	51.0^{c}	

least significant difference (LSD) for KCl effect at $p < 0.05 = 1.579$; LSD for varietal effect at $p < 0.05 = 2.496$

Table 6. Dry weight (g) of seedlings of different tobacco cultivars as influenced by different levels of KCl applications in a pot experiment

Varieties	KCl (mmol kg^{-1} soil)				Mean
	0	4	8	12	
Spt-G.28	9.79	16.73	15.02	13.31	13.71^{a}
KHG-14	7.63	9.03	8.75	8.25	8.42^{c}
KHG-15	5.03	7.06	7.92	5.65	6.42^{g}
KHG-18	5.48	7.13	8.74	6.97	7.08^{f}
Coker-371Gold	6.20	9.03	10.07	7.20	8.13^{d}
Candel	6.01	10.96	12.01	7.22	9.05^{b}
KHG-19	7.01	10.12	9.25	7.50	8.47^{c}
K-399	5.13	10.07	8.15	8.14	7.87^{e}
Coker-48	7.02	9.52	11.63	7.20	8.84^{b}
Coker-176	7.35	12.06	6.51	6.60	8.13^{d}
Mean	6.67^{d}	10.17^{a}	9.81^{b}	7.80^{c}	

least significant difference (LSD) for KCl effect at $p < 0.05 = 0.147$; LSD for varietal effect at $p < 0.05 = 0.233$

averaged across KCl concentration, cultivars showed variation in reducing sugars due to their physiological characteristics. The highest mean reducing sugars of 8.06% was found in Spt-G.28, as compared to 6.26% of Candel. A positive correlation between chloride concentrations in leaves of Virginia tobacco had also been reported by earlier researchers (Karaivazoglou *et al.*, 2005; Collins and Hawks, 1993; McCants and Woltz, 1967), while Marwat and Gul (1992) and Askew *et al.* (1947) reported positive effects of potassium application on reducing sugars.

Table 7. Ash weight (g) of seedlings of different tobacco cultivars as influenced by different levels of KCl applications in a pot experiment

Varieties	KCl (mmol kg^{-1} soil)				Mean
	0	4	8	12	
Spt-G.28	12.53	12.85	12.43	12.38	12.55^{ab}
KHG-14	12.06	12.43	12.38	13.1	12.49^{ab}
KHG-15	12.33	12.51	12.79	12.83	12.62^{a}
KHG-18	12.04	12.52	12.57	13.44	12.64^{a}
Coker-371Gold	12.32	12.05	12.51	13.83	12.68^{a}
Candel	11.97	12.21	12.64	12.58	12.35^{bc}
KHG-19	12.41	12.4	12.37	12.78	12.49^{ab}
K-399	12.64	12.36	11.97	12.36	12.33^{bc}
Coker-48	12.42	12.46	12.55	11.26	12.17^{c}
Coker-176	12.04	11.95	12.04	12.8	12.21^{c}
Mean	12.28^{b}	12.37^{b}	12.43^{b}	12.74^{a}	

least significant difference (LSD) for KCl effect at $p < 0.05$ = 0.267; LSD for varietal effect at $p < 0.05$ = 0.169

Table 8. Reducing sugars (%) of seedlings of different tobacco cultivars as influenced by different levels of KCl applications in a pot experiment

Varieties	KCl (mmol kg^{-1} soil)				Mean	Increase over control (%)
	0	4	8	12		
Spt-G.28	5.21	8.05	9.37	9.61	8.06^{a}	84.45
KHG-14	4.87	6.30	7.43	8.30	6.73^{de}	70.43
KHG-15	4.65	6.40	8.74	9.15	7.24^{bc}	96.77
KHG-18	4.80	6.92	8.34	9.60	7.42^{b}	100.00
Coker-371Gold	4.90	6.02	7.07	7.40	6.35^{fg}	51.02
Candel	4.68	5.54	6.95	7.86	6.26^{g}	67.45
KHG-19	5.01	6.92	8.25	9.20	7.35^{b}	83.63
K-399	5.05	6.25	7.01	8.08	6.60^{ef}	60.00
Coker-48	4.97	6.43	7.29	7.97	6.67^{de}	60.36
Coker-176	5.06	6.94	7.23	8.60	6.96^{cd}	69.96
Mean	4.92^{d}	6.58^{c}	7.77^{b}	8.58^{a}		74.33

least significant difference (LSD) for KCl effect at $p < 0.05$ = 0.196; LSD for varietal effect at $p < 0.05$ = 0.311

Nicotine. Data on nicotine concentrations showed significant effect of KCl applications and cultivars. Nicotine concentrations increased with the application of KCl (Table 9). The highest nicotine concentration of 1.59% was recorded in the treatment receiving 12 mmol KCl kg^{-1} soil as compared to 1.34% in control. Regressing nicotine on KCl showed linear relationship with $r^2 = 0.9571$ (Fig. 1b). Cultivars showed significant difference in nicotine concentration. The highest increase in nicotine concentration was recorded in KHG-18 as 32.31% when compared with control. Coker-371 Gold was found containing the highest nicotine concentration at all KCl levels followed by Spt-G.28, while KHG-15 contained the least nicotine concentration at all KCl levels. Karaivazoglou *et al*. (2005) reported increase in nicotine content due to chloride concentration of irrigation water. However, other researchers like (Collins and Hawks, 1993; Mulchi, 1982; McCants and Woltz, 1967) reported inconsistent effect of chloride on nicotine content in tobacco.

Nitrogen. Like reducing sugars and nicotine concentration, nitrogen concentration of leaf increased with increase in the KCl application concentration. When averaged across cultivars, final nitrogen concentration increased from 1.31 to 1.47%, showing 12.46% increase with application of 12 mmol KCl kg^{-1} soil (Table 10). However, like other parameters, dif-

Table 9. Nicotine concentration (%) of seedlings of different tobacco cultivars as influenced by different levels of KCl applications in a pot experiment

Varieties	KCl (mmol kg^{-1} soil)				Mean	Increase over control (%)
	0	4	8	12		
Spt-G.28	1.47	1.56	1.6	1.76	1.60^{b}	19.73
KHG-14	1.22	1.25	1.4	1.54	1.35^{g}	26.23
KHG-15	1.27	1.44	1.45	1.47	1.41^{f}	15.75
KHG-18	1.3	1.52	1.68	1.72	1.56^{c}	32.31
Coker-371Gold	1.64	1.68	1.73	1.74	1.70^{a}	6.10
Candel	1.39	1.55	1.5	1.5	1.49^{d}	7.91
KHG-19	1.27	1.42	1.44	1.55	1.42^{f}	22.05
K-399	1.25	1.44	1.46	1.55	1.43^{f}	24.00
Coker-48	1.28	1.41	1.54	1.6	1.46^{de}	25.00
Coker-176	1.34	1.4	1.49	1.5	1.43^{ef}	11.94
Mean	1.34^{d}	1.47^{c}	1.53^{b}	1.59^{a}		18.62

least significant difference (LSD) for KCl effect at $p < 0.05$ = 0.023; LSD for varietal effect at $p < 0.05$ = 0.036

Table 10. Nitrogen concentration (%) of seedlings of different tobacco cultivars as influenced by different levels of KCl applications in a pot experiment

Varieties	KCl (mmol kg^{-1} soil)				Mean	Increase over control (%)
	0	4	8	12		
Spt-G.28	0.95	1.07	1.09	1.11	1.06^{f}	16.84
KHG-14	1.06	1.4	1.36	1.38	1.30^{e}	30.19
KHG-15	1.06	1.3	1.39	1.39	1.29^{e}	31.13
KHG-18	1.42	1.45	1.47	1.5	1.46^{c}	5.63
Coker-371Gold	1.28	1.42	1.47	1.4	1.39^{d}	9.37
Candel	1.47	1.52	1.63	1.58	1.55^{ab}	7.48
KHG-19	1.5	1.62	1.58	1.54	1.56^{a}	2.67
K-399	1.33	1.45	1.59	1.61	1.50^{bc}	21.05
Coker-48	1.57	1.48	1.51	1.56	1.53^{ab}	-
Coker-176	1.44	1.56	1.61	1.64	1.56^{a}	13.89
Mean	1.31^{c}	1.43^{b}	1.47^{a}	1.47^{a}		12.46

least significant difference (LSD) for KCl effect at $p < 0.05 = 0.033$; LSD for varietal effect at $p < 0.05 = 0.051$

ferent cultivars showed different responses in the increase of nitrogen concentration. KHG-14 and KHG-15 showed the highest response with increase of 30.19 and 31.13%, respectively, over control, while Coker-48, KHG-19 and KHG-18 showed no or very little increase in the leaf nitrogen concentration with KCl applications. The nitrogen concentrations also varied for different cultivars due to physiological characteristics. Spt-G.28 had lower nitrogen concentrations at all KCl levels as compared to other cultivars with the mean nitrogen content of 1.06%. According to Marwat and Gul (1992), potassium decreased nitrogen content, while chloride increased the nitrogen concentrations in leaf. The increase in nitrogen concentration may be partly associated with the concentration effect (Jarrell and Beverly, 1981), as higher KCl levels significantly reduced plant yield. These results of increasing nitrogen content due to chloride concentration are in conformity with the results of Karaivazoglou *et al.* (2005), but in contrast to McCants and Woltz (1967) who reported a decrease in the total nitrogen content of plants grown at high chloride nutrition. However, nonsignificant effect was found by Mulchi (1982).

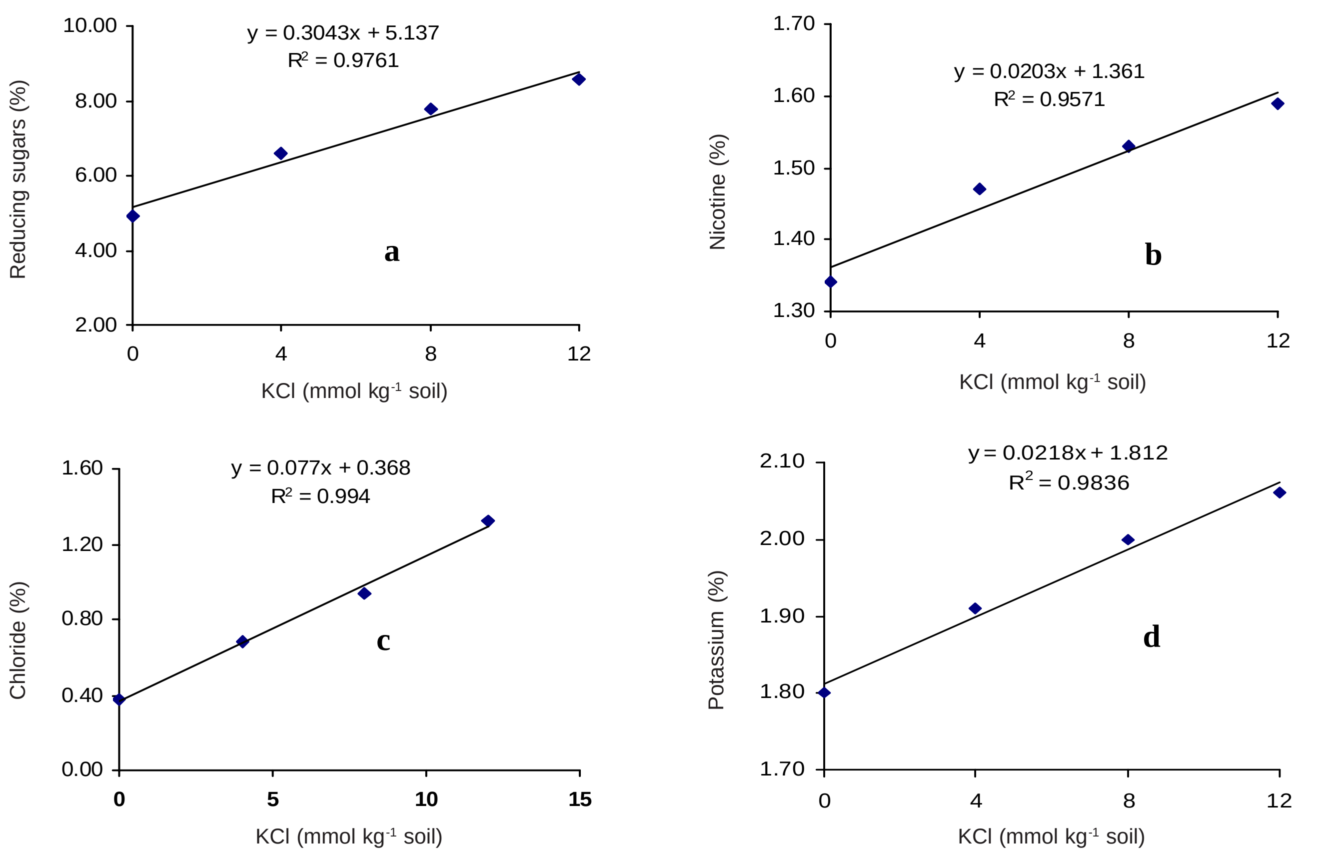

Fig. 1. Effect of KCl application levels on the concentrations of various chemical constituents of leaf: (a) reducing sugars; (b) nicotine; (c) chloride; (d) potassium of Virginia tobacco.

Chloride. Irrespective of cultivars, chloride concentrations were significantly enhanced with increasing levels of KCl (Table 11; Fig. 1c). When averaged across cultivars, chloride concentrations increased from 0.38 to 1.32% with the application of 12 mmol KCl kg^{-1} soil, showing overall increase of 250% over control with a range from 204 to 308% (Table 11). Regression of KCl added on leaf chloride concentration produced positive significant linear relationship ($r^2 = 0.9441$). The magnitude of increases in chloride uptake depended on cultivars. The highest increase of 308% was recorded in Coker-371 Gold, and the lowest of 204.5% in KHG-19. Data on chloride concentrations also showed different concentration for different cultivars. Spt-G.28 contained the least concentration at all KCl application levels, with an average of 0.64%. Potassium and chloride ions react antagonistically, depressing the uptake of each other. Such higher increase up to 308% in the chloride concentration support the suggestion that KCl can produce chloride toxicity in tobacco, when grown on soils already having sufficient amount of chlorides. Many studies have shown significant positive correlation between the chloride concentration in water or soil and the leaf chloride concentration in Virginia tobacco (Karaivazoglou *et al.*, 2005; Peedin, 1999; Collins and Hawks, 1993; Mulchi, 1982; Quresh *et al.*, 1977). It is considered appropriate that an acceptable Virginia tobacco should contain less than 1% chloride. Leaves with higher chloride concentrations are of poor quality with reduced burning rate (Sifola and Postiglione, 2002; Peedin, 1999). If this criterion is implied, it means that all the cultivars produce poor quality tobacco when they received application of 12 mmol KCl kg^{-1} soil.

Potassium. Increasing KCl application from 0 to 12 mmol KCl kg^{-1} soil significantly increased potassium concentration of leaf. When averaged across cultivars, potassium concentration increased from 1.80 to 2.06% showing an overall increase of 14.14% (Table 12). Regression analysis showed linear correlation ($r^2 = 0.9834$) between KCl levels and the potassium concentration in leaf (Fig. 1d). Different cultivars revealed different responses to KCl applications. The highest increase in potassium concentration was found in KHG-14 as 19.16%, followed by Coker-371 Gold and Spt-G.28 with 18.63 and 18.13% increase, respectively, as compared with control. Comparing the magnitudes of increases in potassium ranging from 2.62 to 25.0% and chloride concentrations, which ranged from 204.55 to 308.82% in tobacco leaves, it is suggested that chloride uptake minimized the uptake of potassium in accordance with Karaivazoglou *et al.* (2005).

Conclusions

It may be concluded from this study that low levels of KCl enhanced yield parameters of all tobacco cultivars, while higher KCl concentrations of 12 mmol kg^{-1} soil depressed yield. However, various cultivars responded differently. KHG-14 showed maximum reduction in growth and yield, while KHG-18 and KHG-15 recorded higher increases in reducing sugars, nicotine, chloride and potassium concentrations. Based on overall performance, Spt-G.28 may be regarded as the most suitable variety, which produced greater plant height, number of leaves per plant, leaf area, fresh and dry weight, reducing

Table 11. Chloride concentration (%) of seedlings of different tobacco varieties as influenced by different levels of KCl applications in a pot experiment

Varieties	KCl (mmol kg^{-1} soil)				Mean	Increase over control (%)
	0	4	8	12		
Spt-G.28	0.28	0.53	0.72	1.04	0.64^{f}	271.43
KHG-14	0.34	0.63	1.1	1.18	0.81^{de}	247.06
KHG-15	0.37	0.65	1.04	1.36	0.86^{bcd}	267.57
KHG-18	0.37	0.71	0.96	1.35	0.85^{cde}	264.88
Coker-371Gold	0.34	0.79	0.82	1.39	0.84^{cde}	308.82
Candel	0.44	0.73	1.05	1.42	0.91^{ab}	222.73
KHG-19	0.44	0.79	1.09	1.34	0.92^{e}	204.55
K-399	0.35	0.6	0.9	1.35	0.80^{e}	285.71
Coker-48	0.4	0.64	0.84	1.32	0.80^{e}	230.00
Coker-176	0.43	0.71	0.9	1.44	0.87^{abc}	234.15
Mean	0.38^{d}	0.68^{c}	0.94^{b}	1.32^{a}		250.10

least significant difference (LSD) for KCl effect at $p < 0.05 = 0.036$; LSD for varietal effect at $p < 0.05 = 0.057$

Table 12. Potassium concentration (%) of seedlings of different tobacco varieties as influenced by different levels of KCl applications in a pot experiment

Varieties	KCl (mmol kg^{-1} soil)				Mean	Increase over control (%)
	0	4	8	12		
Spt-G.28	1.82	1.96	2.02	2.15	1.99^{ab}	18.13
KHG-14	1.67	1.85	1.94	1.99	1.86^{f}	19.16
KHG-15	1.91	1.91	1.93	1.96	1.93^{cde}	2.62
KHG-18	1.86	1.93	1.98	2.05	1.96^{bcd}	10.22
Coker-371Gold	1.77	1.88	2.01	2.1	1.94^{bcde}	18.69
Candel	1.70	1.89	1.96	2.05	1.90^{ef}	20.59
KHG-19	1.89	1.98	2.11	2.13	2.03^{a}	12.70
K-399	1.92	1.95	2	2.07	1.99^{abc}	7.81
Coker-48	1.68	1.87	2.05	2.1	1.93^{def}	25.00
Coker-176	1.81	1.92	2.02	1.98	1.93^{cde}	9.39
Mean	1.80^{d}	1.91^{c}	2.00^{b}	2.06^{a}		14.14

least significant difference (LSD) for KCl effect at $p < 0.05 = 0.057$; LSD for varietal effect at $p < 0.05 = 0.036$

sugars and nicotine, and lower levels of nitrogen and chloride as compared to other cultivars. It is suggested that KCl applications should be avoided or applied very carefully to prevent their adverse effects on yield and quality of tobacco as our soils already contain sufficient amount of chlorides. Use of irrigation water with high chloride concentrations may be avoided for tobacco cultivation.

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