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Factors affecting chloride concentration in tobacco: A review

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Abstract

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Chloride is an essential micronutrient for tobacco plants. Small amounts of Cl^- can improve tobacco growth and yield. It is generally accepted that concentrations in excess of 1% can produce poor-quality tobacco. The significant sources of chloride for tobacco plants are soil, Cl-containing fertilizers, and irrigation water. Responses of tobacco to chloride vary according to tobacco types and cultivars. The influence of chloride on the growth, yield, and chemical composition is inconsistent. In general, leaf chloride and reducing sugar concentrations increase with increasing soil or irrigation water chloride levels. Application rates of chloride-containing fertilizers or chloride levels in irrigation water should be monitored to prevent excessive chloride accumulation in tobacco leaves. Plant genetics affect chloride accumulation; therefore, cultivar selection is important in achieving lower chloride concentration in tobacco.

Keywords: tobacco; chloride; soil; fertilization; irrigation water; genotype

Introduction

Chloride (Cl^-) is an essential micronutrient for higher plants and participates in several physiological metabolism processes (Chen et al., 2010). Colmenero-Flores et al. (2019) recently defined chloride as a beneficial macronutrient that increases fresh and dry biomass, determines greater leaf expansion, and increases leaf and root cell elongation. The authors noted that tobacco plants with macronutrient Cl^- levels display more efficient use of water, nitrogen, and carbon/energy. White and Broadley (2001) stated that chloride is a major osmotically active solute in the vacuole and is involved in both turgor- and osmoregulation. In the cytoplasm, it can regulate the activity of key enzymes. The dependence of modern agriculture on irrigation and chemical fertilization highlights the problem of chloride accumulation in soils and its adverse effects on plants, rather than its deficiency (Xu et al., 1999). Chloride deficiency in crop plants causes metabolic problems that inhibit growth (Geilfus, 2018). Some studies indicate that small amounts of Cl^- can improve tobacco growth and yield (Gul et al., 2006; Franco-Navarro et al., 2016; Tabaxi et al., 2020). As a Cl^- sensitive species, tobacco suffers severe damage under conditions of excessive Cl^- supply. Chloride salinity increased the Cl^- content and decreased the relative water content in tobacco, which limited the photosynthetic capacity and reduced photosynthetic products, resulting in decreased levels of auxin and gibberellin (Wang et al., 2020). Excessive chloride also leads to a decrease in dry weight and limits the absorption of nitrogen and potassium in tobacco leaves (Fan and Zhang, 2004). Average concentrations of chloride in plants are in the range of 0.2–2%, which is achieved by irrigation, rain, fertilizers, and air pollution (Chen et al., 2010). Tissue Cl^- concentration exceeding 1% may adversely affect leaf development and quality of flue-cured tobacco (Pace et al., 2020). Smoking quality was good at leaf contents of <1% Cl, acceptable with 1.7–1.8% Cl, and poor with >3% Cl (Kitamura et al., 1978). Excessive uptake of chloride by tobacco produces thickened, brittle leaves with margins curl upwards (Flower, 1999). Cured leaves with excessive Cl have high equilibrium moisture contents, making them very hygroscopic and having low or no fire-holding capacity. Such tobaccos are considered to be of poor quality by the cigarette manufacturers (Tso, 1999). Increased levels of chloride applied to the soil or irrigation water influenced the chemical composition of cured tobacco and cigarette smoke (Fuqua et al., 1976; Karaivazoglou et al., 2005; Gul et al., 2006; Keeney et al., 2021; Tiecher et al., 2023).

The chloride content of the plant depends on the external chloride concentration and the balance of other available anions (Xu et al., 1999). The significant sources of chloride for tobacco plants are soil, fertilizers, and irrigation water (Fan and Zhang, 2004). The responses of tobacco to chloride also vary among tobacco types and cultivars (Karaivazoglou et al., 2006).

The present review focuses on the role of some factors (soil chloride content, chloride fertilization, chloride in irrigation water, and genotypic difference) on tobacco yield, quality, and chemical composition of leaves.

Soil chloride content

Chloride input to soils occurs as a result of depositions of Cl^- from rainwater, fertilizers, irrigation water, sea spray, dust, and air pollution (White and Broadley, 2001). During mineral weathering and soil development, Cl^- is readily leached out at early stages, and Cl^- concentration in most well-developed soils is low unless there is good input from different sources (Chen et al., 2010).

Under conditions of excess Cl^- in the environment, tissue concentrations can exceed toxic levels in crops, reducing yield and quality (Geilfus, 2018). Chloride content in tobacco leaves was positively correlated with soil content of the same element (Tang et al., 2020). High soil Cl^-in some tobacco growing areas in China is one of the main factors for high Cl^- content in tobacco leaves (Shang et al., 2017). On the other hand, Cadersa and Atawoo (2002) noted that no relationship was found between soil chloride and leaf chloride levels. They concluded that other factors may influence chloride uptake and its mobilization in tobacco leaves.

Depending on the chloride content, tobacco growing soils in India are grouped as: very suitable (<80 mg kg^{-1}), suitable (80–100 mg kg^{-1}), and unsuitable (>100 mg kg^{-1}) (Krishnamurthy and Nagarajan, 2001). Yamini et al. (2018) found that the available chloride in the tobacco-growing soils of Prakasam district, Andhra Pradesh, was between 14.2 and 86.0 mg kg^{-1}, indicating the suitability of these soils for tobacco cultivation. Considering the water-soluble Cl^- content, the tobacco-planting soils in China were divided into 5 grades: very low (<5 mg kg^{-1}), low (5–10 mg kg^{-1}), suitable (10–30 mg kg^{-1}), high (30–40 mg kg^{-1}), and very high (≥ 40 mg kg^{-1}) (Xiao et al., 2022). Tan et al. (2016) found that in the Wenshan tobacco growing areas, the chloride content of soil samples was at an appropriate level (10–30 mg kg^{-1}), but the chloride content of flue-cured tobacco leaves was relatively low (chloride concentration in 51.7% of leaf samples was below 0.1%), which is not suitable for the production of high-quality tobacco. According to them, the low chloride content of tobacco leaves was mainly due to the amount and intensity of rainfall that caused leaching. The authors concluded that the application of chloride-containing fertilizers should be recommended to improve tobacco quality.

Geilfus (2019) suggested the following amelioration strategies to increase productivity of Cl^- – contaminated soils: increase of anion exchange capacity in the root zone by incorporation of amendments with high anion exchange capacity, leaching of excess soluble Cl^- from the root zone by ponding, phytoremediation using Cl^- – hyperaccumulators, or providing readily available resources of macronutrient anions for displacing Cl^-. Ishizaki and Akiya (1978) noted that when soil chloride content is high, chloride is removed by irrigation or by growing corn or wheat as preceding crops that absorb chloride. Shang et al. (2017) found that irrigation with chloride channel inhibitors could reduce the negative effect of chloride. Nitrate fertilization might be a strategy to suppress uptake of chloride by means of an antagonistic anion-anion uptake competition when crops are grown on soils that are moderately salinized by chloride (Geilfus, 2018). Fuqua et al. (1976) investigated the effects of NO_3^- and Cl^- fertilization on the yield and chemical composition of burley tobacco. They concluded that increasing the N rate from 112 to 448 kg ha^{-1} resulted in nearly a 35% decrease in Cl^- concentrations at both the 112 and 224 kg Cl^- ha^{-1} rates. Virginia tobacco leaf Cl^- concentration was affected by the interaction of nitrogen fertilizer source and rate of Cl^- application at flowering (Pace et al., 2020). They noted that when 34 kg Cl^- ha^{-1} was applied, calcium nitrate reduced Cl^- assimilation compared to ammonium nitrate and ammonium sulfate. Mulchi (1982) reported that differences in chloride concentrations in Maryland tobacco leaves were not significant among nitrogen sources.

Suitable soil chloride levels and the application of appropriate cultural practices (nitrate fertilization, leaching of excess soluble Cl^- by irrigation, growing preceding crops that absorb chloride) are important for the production of tobacco with desirable cured-leaf Cl^- concentration.

Chloride fertilization

Fertilization with mineral and organic fertilizers can influence the chloride concentration in the soil. The application of Cl-containing mineral fertilizers (KCl, $CaCl_2$, $MgCl_2$, and NH_4Cl) or animal manure contributes to the input of Cl^- to the soil (Geilfus, 2019).

Tobacco is a luxury user of potassium. The preferred source of potassium is potassium sulfate, but the cost of fertilization tempts tobacco growers to use the cheaper muriate of potash source (Palmer and Pearce, 1999). The results of Johnson and Sims (1986) indicate the feasibility of using KCl in the fall as an alternative to K_2SO_4 for burley tobacco, where rainfall is sufficient to leach the Cl^- below the 45 cm soil depth. When properly applied, the muriate of potash source can be safely used by tobacco growers to increase the economic efficiency of fertilizer application (Bozhinova, 2012). Average chloride levels ranged from 0.11% to 0.83% in burley tobacco that received potassium sulfate, and from 1.23% to 3.80% in tobacco that received potassium chloride (Keeney et al., 2021).

The response of tobacco to fertilizer-applied chloride varies with soil type, moisture-holding capacity of the soil, and the amount of rainfall (McCants and Woltz, 1967). The Cl^- anion is very mobile in soil solution, because it does not readily form complexes, and shows little affinity in its adsorption to soil components (White and Broadley, 2001). When precipitation exceeds evapotranspiration, Cl^- easily leaches vertically through water-filled pores away from the root zone (Geilfus, 2019). Johnson and Sims (1986) found that leaf chloride concentration was less than 1% at low KCl levels in the spring, and for all rates of KCl applied the previous fall. They noted that fall application of KCl prior to the following crop year would have minor effects on combustibility if rainfall during the fall and winter is sufficient to leach Cl^- below the main root zone of tobacco plants.

The chloride rate required to reach the quality threshold of 1% Cl content in cured tobacco leaves was site-specific (Tiecher et al., 2023). This conclusion was supported by the studies of Ishizaki and Akiya (1978), who found that when the same amount of chloride was applied, leaf chloride content increased in parallel with the increased amount of application in volcanic ash soils, while leaf chloride content was not affected by chloride application in granite and shirasu soils, as the applied chloride mainly was leached out. Therefore, the critical application rate of chloride-containing fertilizers varies considerably depending on soil properties and rainfall.

Low levels of KCl (4 mmol kg^{-1} soil) enhanced the yield parameters of tobacco, while higher concentrations of 12 mmol kg^{-1} soil depressed the yield (Gul et al., 2006). The authors recommended avoiding the application of KCl or applying it very carefully to prevent adverse effects on tobacco yield and quality, as the soils of Mardan, Pakistan, contain a sufficient amount of chloride. In one of the four growing environments, the chloride rates increased tobacco yield, probably due to the direct effect of Cl as a nutrient (Tiecher et al., 2023). Other researchers reported that leaf yield was not significantly affected by rates of chloride application (Fuqua et al., 1976; Johnson and Sims, 1986; Bozhinova, 2012; Pace et al., 2020). Also, cured leaf quality (grade index value that describes leaf maturity and ripeness) and cured leaf value per hectare were not influenced by Cl application rate (Pace et al., 2020; Tiecher et al., 2023). The results from Keeney et al. (2021) showed minimal effects of potassium chloride applications on the quality grade index. This index was found to be higher in potassium chloride-treated tobacco than in potassium sulfate-treated tobacco in 3 of 10 trials. Significant reductions in average price, quality index, and leaf burn of Maryland tobacco were obtained at rates of chloride application above 44 kg ha^{-1} or above 0.53% chloride in the cured leaf (Mulchi, 1982).

Chloride fertilization of burley tobacco decreased concentrations of the nitrogenous constituents of cigarette smoke but increased total particulate matter and total phenol (Fuqua et al., 1976). According to Keeney et al. (2021), the most consistent effect of potassium chloride application was a 28% reduction in average total tobacco-specific nitrosamines (TSNA) compared to potassium sulfate application. These authors noted that potassium chloride-treated tobacco had an average 38.5% reduction in nitrite compared to potassium sulfate-treated tobacco. They suggested that one possible explanation for TSNA reduction is that nitrate can be antagonized by chloride, leading to lower nitrite and subsequent TSNA formation. Fuqua et al. (1976) also found that nitrate concentrations in burley tobacco leaves were inversely related to the amount of Cl^- applied. Pace et al. (2020) pointed out that factors reducing or limiting N assimilation will also negatively affect alkaloid synthesis. The authors reported that where Cl^- was applied, total N and alkaloids were reduced by an average of 0.17% and 0.23%, respectively, while reducing sugars were increased by 1.67%. Gul et al. (2006) demonstrated that the content of reducing sugars and nicotine in flue-cured tobacco leaves increased at the higher level of KCl (12 mmol kg^{-1} soil) by 74.3% and 18.6%, respectively, compared to the control. Increasing levels of Cl increased the concentration of reducing sugars in flue-cured tobacco and altered the reducing sugars: total alkaloids ratio (Tiecher et al., 2023). Mulchi (1982) found that differences in total nitrogen and total alkaloid levels in Maryland tobacco were not significant among rates of chloride application.

Leaf Cl^- concentration was affected by chloride application rates (Mulchi, 1982; Pace et al., 2020). Chloride concentrations of the cured leaves were increased nearly 15-fold by increasing rates of Cl^- from 0 to 224 kg ha^{-1} (Fuqua et al., 1976). The relationship between the concentration of chloride in Maryland tobacco leaves and the rate of chloride application was linear (Mulchi, 1982). Our own experiments (Bozhinova, 2012) confirmed this observation with Burley tobacco varieties. Chloride concentration in tobacco leaves was highest at the first harvest and decreased to varying degrees at subsequent harvests (Metochis and Orphanos, 1990). The relationships between Cl application rate and the concentration of chloride in tobacco leaves from different stalk positions are presented in Table 1. These equations can be used to predict the maximum chloride rate to keep leaf chloride concentrations from exceeding 1%.

If Y = 1%, the corresponding Cl rates for flue-cured tobacco would be 32 kg ha^{-1} for lower leaves and 120 kg ha^{-1} for upper leaves. The calculated 32 kg ha^{-1} rate is within the range (25–35 kg Cl ha^{-1}) generally accepted for the major flue-cured states in the southeastern USA, but a rate of 120 kg Cl ha^{-1} would increase the risk of leaf quality reduction (Peedin, 1999). Pace et al. (2020) found that flue-cured tobacco leaves from Cl^- treatments ≤34 kg ha^{-1} did not contain Cl^- concentrations in excess of 1%, which would be deemed excessive by industry. Considering the relationships shown in Table 1, the acceptable Cl rates for Burley tobacco would be 79, 136, and 113 kg ha^{-1} for lower, middle, and upper leaves, respectively. These calculated rates are higher than the recommended Cl rate of 65 kg ha^{-1} for producing high cured-leaf quality under South Bulgarian conditions (Bozhinova, 2012). Peedin (1999) summarized that the percent Cl in cured leaves will vary not only with the rates of fertilizers containing chloride, but also with the amount and distribution of rainfall, soil types, and some cultivation practices such as fumigation. Therefore, the equations developed in one country or region may not apply directly to another.

The application of manure is another way for chloride to be deposited in soils. In arid and semi-arid regions without a percolant water regime, Cl^- depositions derived from manures can accumulate in the rooting zone (Geilfus, 2019). The Cl content of manure (FYM) from the main tobacco-producing areas of France varied from 0% to 0.85%. Spring FYM applications can produce tobacco containing up to 2.5% Cl with reduced burning quality, while fall applications have little effect, except in soils with low permeability (Chouteau, 1968). Ishizaki and Akiya (1978) also recommended autumn application of manure to facilitate chloride leaching.

No consistent relationship has been established between chloride rates and tobacco yield, quality, and leaf chemistry. In general, the concentrations of chloride and reducing sugars in cured leaves increased with increasing levels of chloride-containing fertilizers. Depending on the environmental conditions and the type of tobacco, different Cl fertilization rates are recommended without having an adverse effect on the yield and quality.

Chloride in irrigation water

Almost all natural water contains Cl^-, mainly in the form of calcium, magnesium, and sodium salts. Natural water samples from different sources vary in Cl^- content. The Cl^- content in general surface water and groundwater is less than 50 mg L^{-1} (Wu et al., 2021).

Several articles describe the effects of different chloride levels in irrigation water on the agronomic and chemical properties of tobacco. In a pot experiment under greenhouse conditions, Franco-Navarro et al. (2016) reported that under non-saline conditions (up to 5 mM Cl^-) and no water limitation, Cl^- specifically stimulated higher leaf cell size and led to a moderate increase in plant fresh and dry biomass. Tabaxi et al. (2020) found a positive yield response of oriental tobacco to chloride concentration up to 60 mg Cl^- L^{-1} in irrigation water. The highest yield (23.79 g $plant^{-1}$) was obtained from plants irrigated with 30 mg Cl^- L^{-1}, followed by 60 mg Cl^- L^{-1} (18.46 g $plant^{-1}$), 0 mg Cl^- L^{-1} (17.27 g $plant^{-1}$), and 120 mg Cl^- L^{-1} (15.43 g $plant^{-1}$). According to Rosales et al.

Table 1. Relationships between Cl application rate and chloride concentrations in tobacco leaves

Types of tobacco	Leaf stalk position	Equation	Reference
Maryland	A composite sample of leaves	$Y = 0.095 + 1.18 \times 10^{-2}X$, r = 0.94	Mulchi (1982)
Flue-cured	Lower leaves	$Y = 0.014X + 0.556$, $r^2 = 0.99$	Warren (1990), cited in Peedin, (1999), p. 119
	Upper leaves	$Y = 0.003X + 0.637$, $r^2 = 0.95$	
Burley	Lower leaves	$Y = 0.21 + 0.010X$, $r^2 = 0.93$	Bozhinova (2012)
	Middle leaves	$Y = 0.18 + 0.006X$, $r^2 = 0.79$	
	Upper leaves	$Y = 0.10 + 0.008X$, $r^2 = 0.82$	

Y – Cl concentrations in the leaf tissues; X – application rate of chloride-containing fertilizers

Source: Authors' own elaboration

(2020), increased plant biomass indicates that chloride facilitates NO_3^- utilization and improves nitrogen use efficiency in plants. The increased chloride concentration in irrigation water had adverse effects on Virginia tobacco plant growth, total fresh weight and cured leaf yield (Karaivazoglou et al., 2005). They noted that when the concentration of chloride in irrigation water was high, the use of nitrate fertilizers could restrict the negative effects of chloride. Langeroodi et al. (2017) also reported that increasing chloride levels from 10 to 100 mg Cl L^{-1} in irrigation water significantly reduced the number of leaves, dry shoot, and root mass of Virginia tobacco plants. The chloride content of the irrigation water did not affect the commercial value of flue-cured tobacco (Peele et al., 1960).

The concentration of reducing sugars in cured tobacco leaves increased with increasing chloride concentrations in the irrigation water (Peele et al., 1960; Karaivazoglou et al., 2005; Langeroodi et al., 2017; Tabaxi et al., 2020). Soluble sugars act as osmoprotectants, helping to alleviate the adverse effects of salinity on plants (Afzal et al., 2021). In response to chloride salinity, the abscisic acid and metabolites like phenols and sugars in tobacco were increased (Wang et al., 2020). Nemati et al. (2011) suggested that high total soluble sugar concentration in the shoot of salt-tolerant rice genotype is probably for adjusting osmotic potential and better water uptake under salinity. The effect of chloride on the nicotine content of oriental tobacco leaves showed an inconsistent trend (Tabaxi et al., 2020). They found that the highest nicotine content was in plants irrigated with 30 mg Cl^- L^{-1}, followed by 0 mg Cl^- L^{-1}, 60 mg Cl^- L^{-1}, and 120 mg Cl^- L^{-1}. A similar inconsistent effect of chloride in irrigation water on the nicotine content of Virginia tobacco was reported by Peele et al. (1960) and Langeroodi et al. (2017). Nicotine concentration increased mainly in plants treated with nitrate nitrogen (Karaivazoglou et al., 2005).

Leaf chloride concentration increased with the increase of chloride level in irrigation water (Metochis and Orphanos, 1990; Karaivazoglou et al., 2005; Karaivazoglou et al., 2006; Langeroodi et al., 2017). Irrigation water chloride content and irrigation times can affect the chloride content of flue-cured tobacco leaves significantly (Guo et al., 2019). The increase in chloride percentage in Virginia tobacco with increasing seasonal water amounts (irrigation water applied containing a very high concentration of chloride) was highlighted by Çakir and Çebi (2010). They proposed regression models to predict the average chloride percentage in tobacco leaves based on the amount of irrigation water. The average increase in percent chloride in the cured leaf was 0.009 for each pound of chloride added by the irrigation water (Peele et al., 1960).

According to Tabaxi et al. (2020), it is preferable to use irrigation water with a chloride content of up to 30 mg Cl^- L^{-1}, because at this level the chloride concentration in the leaves remains up to 1.5%, which is considered generally acceptable for Oriental tobacco. The optimum chloride level in irrigation water was found to be below 20 mg L^{-1}, whereas the 40 mg L^{-1} level was the critical upper threshold to avoid adverse effects on Oriental tobacco (Karaivazoglou et al., 2006). Another study with Virginia tobacco has shown that the chloride level in irrigation water should also be below 20 mg/L. In contrast, the level of 40 mg/L in combination with nitrate nitrogen fertilizers can be considered as the upper threshold to avoid adverse effects of chloride on tobacco plants (Karaivazoglou et al., 2005). Langeroodi et al. (2017) recommended that the chloride level in irrigation water should be below 25 mg/L for acceptable Virginia tobacco. The same authors noted that a level up to 40 mg L^{-1}, in combination with arbuscular mycorrhizal fungi (AMF), can be considered an upper threshold. AMF symbiosis alleviates the negative effects of salt stress in tobacco plants by altering hormone production and affecting plant physiology. Guo et al. (2019) established that to control the chloride content of flue-cured tobacco leaves within the appropriate range of 0.3%-0.8%, the tobacco plant should be irrigated by low chloride water (7.7 mg L^{-1}), medium-chloride water (24.6 mg L^{-1}) irrigation should be limited, and high-chloride water (43.2 mg L^{-1}) irrigation should be avoided.

Chloride is an essential micronutrient for tobacco plants, but high levels in irrigation water can result in growth inhibition, reduced yield, and increased leaf chloride concentration. Therefore, it is important to monitor chloride levels in irrigation water to avoid adverse effects on both agronomic performance and chemical composition of tobacco.

Cultivar differences in chloride assimilation

Cultivar differences in resistance to Cl^- toxicity are generally inherited and related to the ability of the root to limit Cl^- transport to the shoot (White and Broadley, 2001). Chloride-sensitive cultivars accumulate excessive Cl in shoots, and tolerant cultivars limit Cl transport to shoots (Xu et al., 1999).

Some studies have shown that levels of chloride differ among tobacco cultivars. Darvishzadeh et al. (2011) observed that the Cl concentration of 100 oriental and semi-oriental tobacco genotypes ranged from 0.38% to 2.68% and suggested that Cl concentration is genetically controlled. The Oriental tobacco cultivars showed different levels of chloride in leaves, and element concentration was differentially affected by increased chloride in water (Karaivazoglou et al., 2006; Tabaxi et al., 2020). We also observed significant variety differences in chloride accumulation in Burley tobacco cultivars (Bozhinova, 2012). Ten Virginia tobacco cultivars showed a different response to KCl-induced chloride toxicity, and one of them (Spt-G.28) appeared to be the most suitable with a lower chloride level compared to other cultivars (Gul et al., 2006). According to Darvishzadeh and Alavi (2011), the effects of general combining ability and specific combining ability on chloride concentration were highly significant, indicating that both additive and dominant gene effects are important in controlling chloride concentration in oriental tobacco genotypes. Using the mixed linear model procedure, 1 SSR locus (pt30027) from linkage group 13 was identified to be associated with the gene(s) controlling low chloride accumulation in oriental tobacco genotypes (Basirnia et al., 2014). The soluble sugar accumulation rate of the Basma variety was significantly higher than that of K326 after 12 h of NaCl stress, indicating that Basma had faster osmotic accumulation regulation and stronger resistance to salt stress than cultivar K326 (Wang et al., 2023).

These studies show that cultivar selection can be used to minimize Cl effects associated with high soil Cl^- content, application of chloride-containing fertilizers, and use of high-chloride irrigation water.

Conclusions

Chloride is an essential micronutrient for tobacco plants, but high levels in soil, fertilizers and irrigation water can result in growth inhibition, reduced yield and quality of cured leaves. Cured leaves with excessive chloride are considered to be of poor quality by the cigarette manufacturers.

This review presents data on the influence of some factors (soil chloride content, chloride fertilization, chloride in irrigation water, and genotype) on tobacco yield, quality, and chemical composition of leaves.

Suitable soil chloride levels and the application of appropriate cultural practices (such as nitrate fertilization, leaching of excess soluble Cl^- by irrigation, and growing preceding crops that absorb chloride) are important for producing tobacco with a desirable cured-leaf Cl^- concentration. No consistent relationship has been established between chloride fertilization rate and tobacco yield, quality, and leaf chemistry. In general, the concentrations of chloride and reducing sugars in cured leaves increased with increasing chloride application rate. Depending on the environmental conditions and the type of tobacco, different Cl^- fertilization rates are recommended to prevent adverse effects on the yield and chemical composition. It is important to monitor chloride levels in irrigation water to avoid adverse effects on both agronomic performance and the chemical composition of tobacco. The optimum chloride level in irrigation water was found to be below 20–30 mg/L. A higher level of chloride (40 mg L^{-1}) can be considered as an upper threshold only when applied in combination with nitrate fertilizers or arbuscular mycorrhizal fungi.

When Cl^- levels in soil and irrigation water are high, cultivar choice provides options for the production of tobacco with lower chloride content.

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