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Potassium Deficiency Could Occur First on Middle and Upper Leaves but not on Lower Ones

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Abstract **– Objective: It is generally believed that plant K deficiency occurs firstly on old mature leaves if plant is in inadequate supply of K. But in fields with flue-cured tobacco plants applied adequate K, suspected K deficiency (SPD) symptoms occurred on middle, even on upper leaves, but not on lower ones. Whether it is really K deficiency is unclear. Methods: Plants growth was monitored in field and samples of leaves and rhizopheric soils were collected from plants healthy and with SPD symptoms respectively for two *Nicotiana tabacum L.* varieties K326 and Yunyan 87 and potassium concentration analyzed.** Results: **Even under the normal weather condition and with no occurrence of diseases and pests, flue-cured tobacco plants of varieties K 326, Yunyan 87 and Yunyan 97 (not sampled) in different fields all supplied with adequate potassium fertilizer showed the suspected potassium deficiency symptoms on middle and upper leaves but not on lower ones almost before and after the excision of apex. The symptoms were nearly the same as one typically described for potassium deficiency of lower leaves. Although potassium concentration in leaves both decreased with the position upwards, plants with SPD symptoms had lower K^+ concentration in leaves on different position of stalk than the normal ones for the two varieties. Meanwhile, the available potassium content in the rhizospheric soils was found lower for SPD plants, by 36.76% for K326 and 36.42% for Yunyan 87 respectively. Conclusions: It could be concluded that it was indeed potassium deficiency that resulted into the occurrence of SPD in middle and upper leaves of tobacco plants which had normal lower leaves.**

Keywords **– Flue cured Tobacco, K Deficiency, Symptom, Leaf K Concentration, Soil Available K.**

I. Introduction

Potassium (K) is one of the essential elements for plant growth and development. It plays an important role in the regulation of plant cell osmotic potential [4], enzyme activity [18], photosynthesis and carbon hydrates transport etc. Therefore, potassium influenced crop yield or quality greatly ([6], [11], [19]). However, unlike nitrogen (N) and phosphorus (P), K is not metabolized and it forms only weak complexes in which it is readily exchangeable [19]. It is characterized by strong mobility [14] and high degree of reutilization in plants at all levels ([3], [21]). When K is deficient, growth is retarded and net transport of K+ from the old mature leaves and stems transfers to the upper new organs, to ensure normal growth ([10], [12]). Therefore, in most cases K deficiency occurs mostly not in plant early growth but in plant later growth. Meanwhile, margin and tip chlorosis or brown spots could be found on lower leaves, followed by a gradual necrosis, and there is a marked gradation in the severity of the symptoms from old to young leaves ([12], [13]).

Flue-cured tobacco is one of the widely cultivated cash crops around the world, especially with maximum planting area in China [8]. During its growth and development, tobacco plant absorbs K far more than the other nutrient elements [9, 15]. Meanwhile, as flue-cured tobacco leaves' yield and quality are greatly affected by K ([1], [7]), farmers usually apply two to three times more K fertilizer than N fertilizer in the production [22]. Therefore, K deficiency symptoms should not occur theoretically for the healthy flue-cured tobacco plants supplied adequate K fertilizer under normal climate condition. However suspected K deficiency symptoms of leaves occur frequently in fields with flue-cured tobacco planted. Of course, it occurs not on the traditionally understood old mature leaves but on the relatively young ones on the middle and upper position of the stem ([5], [9], [20])! Whether such symptom is really K deficiency, and how it differs from the ones occurring on old mature leaves acknowledged generally, are unclear.

The aim of the current paper was to elucidate whether such symptom is really related to K deficiency of flue-cured tobacco plant.

II. Materials and Methods

A. Site Description, Soil Properties, and Weather Conditions

Field experiments were carried out in May to July, 2014 in Ziwu town, Chuxiong, Yunnan province, Southwestern China. The soil, classified as a typical red soil in China, was acidic (pH 6.12 in 1:1 soil: water) and had a middle organic matter content (22.7 g/kg) and had a loamy texture. The crops were cultivated according to the local tradition with rapeseed in the winter-spring season and flue-cured tobacco in the spring-summer season.

Table 1. Comparison of the average temperature and precipitation data during May to July

Month	Mean temperature (°C)		Precipitation (mm)	
	2014	average in recent ten years	2014	average in recent ten years
May	21.0	20.5	16.7	76
June	21.8	22.0	67.0	138
July	21.7	22.0	210.9	186

Air temperatures and precipitation during May to July are shown in Table 1. The mean temperatures during these three months in 2014 are usually similar as those in the recent ten years, while the precipitation in May and June were much lower in 2014.

B. Plant Growth and Management

Three *Nicotiana tabacum L.* varieties including K326, Yunyan 87 and Yunyan 97 were cultivated in Ziwu town. Despite of the varieties' difference, the procedure and management for seedlings' nursery were all identical. Seeds were germinated in a mixture of 60% (w/w) peat culture substrate, 20% ground maize stalk, and 20% perlite. The seedlings were grown in this mixture in a seedbed in a naturally illuminated glasshouse until they reached the normal transplanting stage for tobacco production. Tobacco seedlings were transplanted into the fields in rows 110 cm apart with 60 cm between plants within each row. According to the local recommended practice, transplanting seedlings received different amounts of fertilizer due to the varieties' difference, i.e., K326 variety fertilized at 120 kg N, 162 kg P_2O_5 and 364 kg K_2O per hectare, while Yunyan 87 fertilized at 128 kg N, 128 kg P_2O_5 and 422 kg K_2O per hectare and Yunyan 97 at 120 kg N, 158 kg P_2O_5 and 374 kg K_2O per hectare. Part of the fertilizer was applied before transplanting, i.e., the field received 50% of the N rate, 60% of the K rate, and 100% of the P rate with a 15-15-18 N-P_2O_5-K_2O compound fertilizer and calcium superphosphate (16% P_2O_5) and potassium sulfate (50% K_2O). The rest of the N and K fertilizer was divided into two equals and dressed as KNO_3 at 15 and 25 days after transplanting respectively. Plants were irrigated and weeds were manually controlled when needed during the experiments. Cultural practices were those recommended for Virginia tobacco in the area by the Tobacco Company of Chuxiong (2014). The inflorescence was removed from each plant when plants had produced 18-20 leaves, and suckering was manually controlled according to the recommended methods.

Plants' growth condition i.e. deficiency symptoms of leaves on different position, was monitored weekly. It was found that nearly blossoming stage some plants appeared deficiency symptoms on leaves of middle and upper position of stem which is similar to traditionally recognized K deficiency, while the lower leaves on the same plant grew normally. Of course, there were some plants in field which grew normally and did not appear deficiency symptoms on all leaves. The consistent occasion appeared in fields grown K326, Yunyan 87 and Yunyan 97 respectively (Table 2).

Table 2. Position of leaves showing deficiency symptoms similar to traditionally recognized K deficiency of flue-cured tobacco plants in fields

Variety	Nearly blossoming stage		Period after excision decapitation	
	Leaves number showing suspected K deficiency	Leaves number showing obvious symptom	Leaves number showing suspected K deficiency	Leaves number showing obvious symptom
K326	15-top	11, 13	16-top	12, 13
Yunyan 97	13-top	14-21	11-top	12-14
Yunyan 87	10-top	10, 14	11-top	13-14, 17

Note: Numbers in table represent leaf position, increasing gradually from bottom to top, the same as the following.

According to the performances of tobacco plants, varieties K326 and Yunyan 87 were selected for the subsequent sample and analysis. The inflorescence was removed from each plant when plants had produced 18-20 leaves, and suckering was manually controlled according to the recommended methods.

C. Harvest Procedures

Harvest and Analysis of Plant Samples

When the apices were removed from the plants for 10 days, upper leaves (the 17^{th}–18^{th} pieces), middle leaves (the 11^{th}–12^{th} pieces), and lower leaves (the 5^{th}–6^{th} pieces) were sampled from plants in normal growth (NG) and plants with suspected potassium deficiency (SPD) respectively for each of two varieties, K326 and Yunyan 87. For further statistical analysis, sampling was repeated 4 times.

The fresh weight of the bulked leaves parts was recorded, and the samples were then dried at 65 °C to a constant weight before dry weight was recorded. The parts were then ground to pass through a 250-mesh sieve. Parts of the samples were weighed and burned at 550 °C. The ashes were dissolved in diluted hydrochloric acid. The content of K^+ in the solution was determined by flame photometry [16].

Harvest and Analysis of Soil Samples

The rhizospheric soils of sampled plants were also collected. The soil around the plant in a 0.3 m^2 area and 0.3 m deep was excavated. The shaken rhizospheric soils were collected, air-dried in a cool and dry place, and sieved through a 20-mesh screen. Parts of the samples were weighed and extracted by 1 mol/L ammonium acetate. The content of K^+ in the solution was determined by flame photometry [2].

The unit used to represent the K^+ content of each sampled leaf was %, and the corresponding K^+ content in rhizospheric soils was indicated by mg/kg.

D. Statistical Treatment

Determinations of the leaf K^+ content and soil available K were obtained from four replicates for harvests. Each leaf and soil was analyzed individually and each analysis was done with two replicates of extraction and two or three independent measurements per extraction. Analysis of variance (ANOVA) for results was performed by the procedure SPSS release 17.0.

III. Result

A. Appearance of Middle and Upper Leaves with the Degree of SPD in Different Tobacco Varieties

As shown in Figures 1 and 2, suspected potassium deficiency was observed in the middle and upper leaves, but not in lower leaves, before and after the excision of apex for tobacco plants even fertilized as the normal ones. Two varieties, K326 and Yunyan 87, both showed the same symptoms.

In general, the whole tobacco plants grew well even before or after apex excision, in terms of the height, general color, leaves length and width (Fig. 1(a), 1(b) and 2(a), 2(b)), except that the leaf tips and margins of middle and upper leaves turned yellow and curled to the outside and showed necrotic tissue. These symptoms were indicative of potassium deficiency (Fig.3).

Fig. 1. Suspected potassium deficiency (SPD) plant and leaves' appearance of variety K326
Note: 1(a): SPD tobacco plant in blossoming stage; 1(b): SPD tobacco plant after topping; 1(c): upper leaves of SPD.

Fig. 2. Suspected potassium deficiency (SPD) plant and leaves' appearance of variety Yunyan 87.
Notes: 2 (a): SPD tobacco plant in blossoming stage; 2(b): SPD tobacco plant after topping; 2(c): upper leaves of SPD plant; 2(d): Middle leaves of SPD plant; 2(e): Lower leaves of SPD plant.

International Journal of Agriculture Innovations and Research
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B. Comparison of the K+ Concentration in Leaves between Normal Growth Plants and SPD Plants

As shown in Figure 4, lower leaves had highest K^+ concentration, followed by middle leaves and upper leaves, in spite of the difference in genotype and management between two tobacco varieties, i.e. K 326 and Yunyan 87. In addition, what's more important is that normal plants had higher K^+ concentration in leaves on different position of stalk than the ones with SPD symptoms. Particularly, the K^+ concentrations in the upper leaves of normal plants for variety K326 and in the middle and upper leaves of well growth plants for Yunyan 87 were significantly higher than those in the corresponding leaves of plants with SPD, by 9.51%, 15.47%, and 16.16% respectively. These results suggested that the occurrence of SPD in the middle and upper leaves was mainly due to their own relatively lower K^+ concentration.

Fig. 3 Symptoms of typical K deficiency and SPD in leaves of flue-cured tobacco
Note: 3(a): SPD in upper leaf of flue-cured tobacco; 3(b): SPD in middle leaf of flue-cured tobacco.

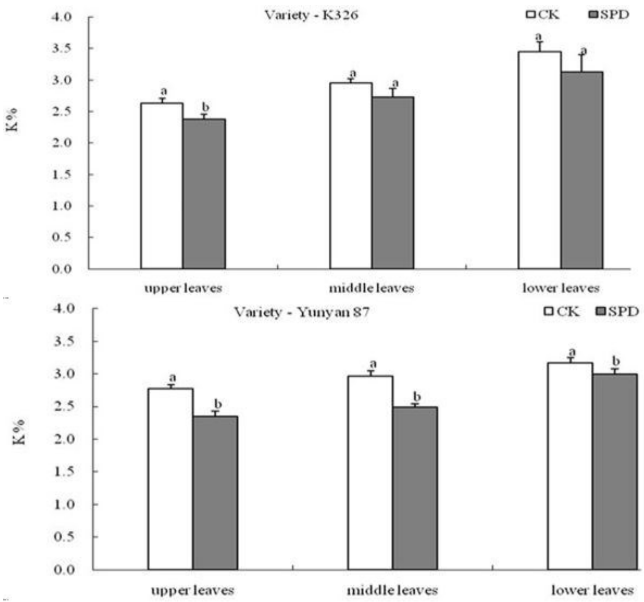

Fig. 4. Potassium concentration in leaves of normal growth plants (CK) and suspected potassium deficiency ones (SPD) (*Note*: means within the same set of rectangles by the different small letters are significantly different at 5% level).

C. Comparison of the Available Potassium Content in Rhizospheric Soils between Normal Growth Plants and SPD Plants

As shown in Figure 5, even though the available potassium content differed between two tobacco varieties, the consistent trend had been found. The available potassium content in the rhizospheric soils of normal growth tobacco plants was significantly higher than that of SPD plants, by 36.76% for K326 and 36.42% for Yunyan 87 respectively. It further revealed that SPD in the middle and upper leaves of tobacco plants was related in some extent to the availability of potassium in rhizospheric soil.

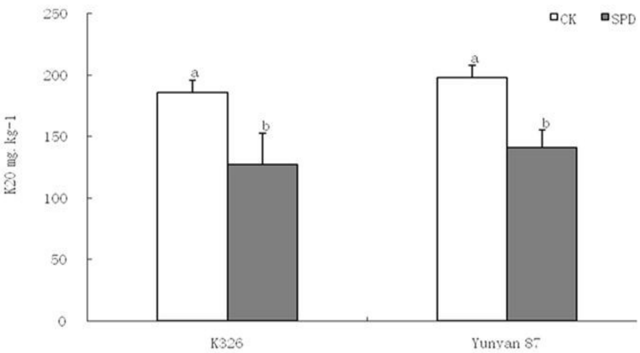

Fig. 5. Available potassium content in rhizospheric soils of normal growth plants (CK) and suspected potassium deficiency ones (SPD) (*Note*: means within the same set of rectangles by the different small letters are significantly different at 5% level)

IV. Discussion and Conclusion

Potassium is a highly mobile mineral element in plants, which does not form a stable compound and could be transferred to the vigorous organs if necessary. Therefore when the plants are deficient in potassium, it is commonly recognized that potassium deficiency symptom appears in old leaves first [10]. But contrary to the common knowledge, the study demonstrated that suspected potassium deficiency (SPD) occurring in the middle and upper leaves, not in lower leaves is frequently found in tobacco-growing fields despite of the difference of varieties, sites or years. On the occasion, the leaf tips and margins of middle and upper leaves of varieties i.e. K326 and Yun 87, turned yellow and curled to the outside and showed necrotic tissue, while lower leaves grew normally and had no sign of any deficiency. The symptoms occurring in middle and upper leaves of tobacco plants were much consistent with the common manifestation of potassium deficiency in the lower leaves described in field of plant nutrition.

Plant nutrient analysis reflects the real nutritional status under strict conditions, while the analysis of soil nutrients can indicate the availability of nutrients for absorption by the root system under conditions favorable to growth [12]. Therefore, the combination of these 2 methods can allow the more accurate determination of whether the observed

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leaf pathology was caused by potassium deficiency in the study. The results of these experiments indicated that the potassium concentration in the tobacco plants with SPD was significantly lower than that in leaves at the same position of normal tobacco plants. Additionally, there were even significant differences for the upper leaves of tobacco K326 and for the middle and upper leaves of tobacco Yun 87 between tobacco plants with or without SPD, suggesting that the potassium concentration in leaves was closely related to the occurrence of SPD.

Meanwhile, the available potassium in rhizosphere soils is the direct source of potassium for the growth and development of crops, which could reflect the availability of potassium in soils to some extent. Under the normal environmental conditions, the occurrence of plant potassium deficiency was correlated with the amount of available potassium in rhizosphere soils. The results also showed that the available potassium content in the rhizosphere soils of 2 tobacco varieties with SPD were significantly lower than that of normal plants. These findings revealed that, under the condition of a lower content of available potassium in soil, tobacco plants could not obtain enough potassium to sustain the growth and health of their leaves, thus resulting into lower concentration of potassium and corresponding occurrence of SPD in leaves. Once it had also been reported that under favorable growth conditions, suddenly cutting off the supply of certain mineral nutrients to roots will lead to further transport of nutrients in different ways. Nutrient loss in young leaves was faster than that in old leaves [17]. However, this experiment was a field trial. Although the amount of available potassium in the rhizosphere soils of tobacco plants with SPD in middle and upper leaves was relatively lower, the supply was sustainable without any sudden cut-off.

Therefore, based on the deficiency symptoms and potassium concentration of leaves as well as soil available potassium content, it could be concluded that it is indeed potassium deficiency that resulted into the occurrence of SPD in middle and upper leaves of tobacco plants which had normal lower leaves. However, further research is necessary to explain this phenomenon, which is inconsistent with the conventional redistribution theory of mineral nutrition.

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