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The Importance of Potassium Buffer Power in the Growth and Yield of Cardamom

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ABSTRACT

Cardamom (*Elettaria cardamomum* M.), one of the world's most valuable spice crops, has very high potassium (K) requirement and the K fertilizer recommendations for it are routinely made on the basis of NH_4OAc extractable K which has not given satisfactory results in many instances. When prices of K fertilizers escalate, as has recently happened in India, and the K fertilizer recommendations are unreliable, farmer confidence will be at risk. This investigation was initiated to test whether, as an alternative, determination of the K buffer power of the soils and its integration into routine soil test K data would result in better predictability of soil K availability. Results showed that as opposed to a non-significant low r value between NH_4OAc extractable K and leaf K in the absence of the K buffer power, its integration resulted in a very highly significant r value explaining nearly 44% of the variation in leaf K. Soil samples and leaf samples were obtained from 94 locations on nearly 20,000 ha in the two most important cardamom growing states of Southern India. Capsule yield was closely related to the K buffer power of

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the soils and not NH_4OAc extractable K and it is suggested that a re-orientation of K fertilization schedule based on K buffer power of the soils, rather than merely on NH_4OAc extractable K, might lead to better and more reliable K fertilizer recommendations.

INTRODUCTION

Cardamom (*Elettaria cardamomum* M.), one of the world's most valuable spice crops, grows in about 93,000 ha in India and is chiefly confined to the southern states Kerala and Karnataka. It has very high potassium (K) requirement and to obtain a normal crop of about 100 kg dry capsules ha^{-1}, about 150 kg K_2O ha^{-1} is recommended to be applied (Sadanandan et al., 1993a).

The K fertilizer prescriptions for cardamom are based on routine normal neutral ammonium acetate extraction, which has not given satisfactory results. Ammonium acetate extraction quantifies exchangeable K and the most important reason why it fails to provide a reliable index of K availability for cardamom is that a mere extraction with this extractant will not provide information, for instance, on K supply from inter-layer minerals which might form an important and slow releasing K pool, especially relevant in the case of slow-growing, deep-rooted, and long-duration crops such as cardamom. On an average, a cardamom plantation can grow for as long as 25 years and because of this very long duration it would be imperative to subject soil testing methods for K availability to more rigorous scrutiny if reliable K fertilizer recommendations have to be made. The importance of K supply from inter-layer minerals, even in the case of short-duration annual crops, such as rye grass (*Lolium perenne* cv. Taptoe) has recently been stressed (Mengel and Uhlenbecker, 1993).

For the first time, Mengel and Busch (1982) demonstrated that the critical K^+ level in the bulk soil solution was related to the K buffer power, thus emphasizing the great importance of this parameter in regulating K supply to growing plant roots. The critical K concentration is higher the lower the K buffer power and *vice versa*. Mengel and Kirkby (1982) have explained how an intrinsic relationship between K-quantity and K-intensity, which the K buffer power represents, regulates K supply to plant roots. Potassium is essentially transported from soil solution to root surface by diffusion. Thus, flux rates depend on the K concentration gradient between root surfaces and the bulk soil solution. Though the bulk K concentrations of most arable soils equilibrated with adsorbed soil K is in the range of 0.1 to 1.0 mM (Mengel, 1993), it is far higher than the K concentration adjacent to K-absorbing root surfaces which is only in the range of a few μM (Claassen et al., 1981). This indicates that the K buffer power would be a very important parameter governing K supply to plant roots. In a recent review on the buffering of plant nutrients and effects on their availability (Nair 1996), it has been indicated that an estimation of K buffer power, instead of the routine estimation of available K by extraction with normal neutral ammonium acetate, might provide a better and more precise estimation of soil K availability. Since the K concentration at the root surface, which is crucial to K uptake, is directly related to the K buffer power (Nair, 1996), an estimation of the soil's K buffer power, instead of the routine NH_4OAc extractable K, might provide a more meaningful index of K availability for cardamom. This hypothesis has never before been tested in this crop. Prevalent market forces in India have steeply pushed up the price of potassic fertilizers and if farmers' confidence has to be restored in sound K fertilizer recommendations for perennial crops such as cardamom, an alternative approach based on the K buffer power concept might be warranted. This investigation, therefore, was initiated to test that hypothesis and covered an extensive area of approximately 20,000 ha.

MATERIALS AND METHODS

The Crop and Its Geographic Locations

Cardamom has its origin in the evergreen forests of the Western Ghats of Southern India and is grown within 8°30'-14°N latitude and 75°-17°E longitude. It is an extensive tract covering more than 1200 km² and is grown at an elevation ranging from 500-2,000 m above mean sea level. The climate is tropical humid with temperature ranging from 10°-32°C and relative humidity ranging from 85-95%. Mean rainfall varies from 1,250-4,800 mm, most of which is received during the South-West monsoon period (May to October). Certain areas can receive as much as 50 mL of water per day for about 100 days which is followed by long dry

TABLE 1. Selected important chemical properties of the soils.[a]

Property	Region	
	Coorg	Idukki
Organic carbon (%)	2.8 (0.81-6.1)	2.7 (1.4-4.5)
pH (H_2O, 1:2)	5.3 (4.3-6.1)	5.2 (4.7-5.9)
CEC (Cmol (p^+) kg^{-1} soil)	28.3 (8.6-58.5)	22.3 (13.0-31.2)
NH_4OAc extractable K (mg kg^{-1} soil)	163(13.0-778.0)	195 (35.0-697.0)
HNO_3 extractable K (mg kg^{-1} soil)	388(26.0-1294.0)	782 (318.0- 1214.0)

[a]The values given in this table are means of 58 samples from Coorg and 36 samples of Idukki soils. Values within parenthesis refer to the range in each case.

spells (Sadanandan et al., 1993b). Unless replanted, the cardamom plant can grow for as long as 25 years.

The Soils

The major cardamom growing soils belong to the order alfisols and suborder ustalfs derived from schists, granites, and gneiss and are formerly called lateritic soils. The soil texture varies from sandy clay to clay loam. They are deep, well-drained soils with Kaolinite predominating in the clay fraction. The pH ranges from 5.0 to 6.5. Table 1 summarizes the important chemical properties of the soils of the two regions, namely, Coorg (in Karnataka State) and Idukki (in Kerala State) where the experiments were located.

Soil and Plant Sampling

After a preliminary survey of the two regions, 94 locations (58 from the Coorg region and 36 from the Idukki region) were established in farmers fields. The crop in these plantations was fertilized with prescribed rates of K fertilizer (muriate of potash) as per soil test values obtained by ammonium acetate extraction. From each location, 5 samples of 500 g each were taken at a depth of 0-20 cm in the root zone of tagged plants. At the same time, leaf samples, the fifth pair counted from the top of each panicle bearing tillers, were also taken as per normal procedure (Sadanandan et al., 1993b). Soil samples were air dried, sieved (2mm), and analyzed for exchangeable K by extraction with 1N ammonium acetate (pH 7.0) (Pratt, 1965) and 1N HNO_3 extractable K (Wood and De Turk, 1941) was also determined. Oven dried (70°C) to constant weight leaf samples were milled and analyzed for K by wet digestion diacid method using a HNO_3-$HClO_4$ mixture (Jackson, 1965) and the K in the digest was determined using a Varian AA20 computerized Atomic Absorption Spectrophotometer. Harvesting for yield was done when the capsules matured and progressive total yield per plant was computed from the tagged plant. In this method, seasonal and location specific variations do not arise. The main contributory factor in yield differences is the soil factor of which K supply is primary as we shall observe below.

Establishment of the Potassium Buffer Power of the Soils

Mengel and Kirkby (1982) defined K buffer power as follows:

$$B_K = \frac{Q}{I}$$

where B_K = K buffer power, Q = K quantity and I = K intensity. In the present investigation, we regressed NH_4OAc extractable K on HNO_3 extractable K and the b values obtained in the regression functions were taken as an approximation of the K buffer power rather than the actual K buffer power of the soils investigated. Hence, there is a qualitative difference from the original procedure adopted by

TABLE 2. Potassium buffer power of the experimental soils.[a]

Region	Regression function (Y=a+bx)	r
Coorg	142.38 + 1.44 bx	0.856***
Idukki	592.46 + 0.92 bx	0.580***

[a]The K buffer power was calculated by regressing NH_4OAc extractable K(x) over HNO_3 extractable K (Y) representing K-intensity and K-quantity, respectively. The b values in the regression functions, 1.44 for Coorg region and 0.92 for Idukki region represent the K buffer power respectively of these soils. The r values refer to the correlation between NH_4OAc extractable K (x) and HNO_3 extractable K (Y)*** significant at 0.1% confidence level.

Mengel and Busch (1982) to determine K buffer power and what has been accomplished in this investigation. As a working hypothesis, our procedure appeared to be sound as we shall see subsequently.

There were 94 pairs of values, 58 referring to the Coorg region and 36 referring to the Idukki region. Regression functions were separately established for both the regions by regressing NH_4OAc extractable K over HNO_3 extractable K, which was considered as approximations of K intensity and K quantity, respectively (though in reality NH_4OAc extractable K might refer more to K quantity and HNO_3 might extract even inter-layer K denoting more than K quantity). Also, the 94 pairs of values, irrespective of the regions, were pooled and the regression functions established. Results are in Table 2. A perusal of the r values indicate that there is a very high degree of closeness between NH_4OAc extractable K and HNO_3 extractable K, the correlation coefficients (r values) being very highly significant (0.1% confidence level). From this, it can be inferred that the analytical procedures adopted permitted a precise estimation of the K supplying capacity of the soils investigated, which we shall propose, for recommendatory purposes, as a working hypothesis of the K buffer power of the soils. Besides, these procedures allow operational ease in routine laboratory testing. The slope of the regression functions, which the b values represent in Table 2, indicate that the Coorg soils are nearly twice higher in their K buffer power as compared to the Idukki soils and we shall examine how this varying K buffer power has affected cardamom yield.

Effect of Potassium Buffer Power on Leaf Potassium Concentration

Data on leaf K and corresponding data [illegible] NH_4OAc extractable K and HNO_3 extractable [illegible] given in Table [illegible]

TABLE 4. Correlation coefficients between routine soil test K data [NH_4OAc extractable K (x)] and leaf K [% K concentration (Y)].

Region	Correlation coefficient (r)
Coorg	0.206
Idukki	-0.001
Combined (pooled data for both regions)	0.1754

properties, such as CEC, organic carbon, and soil pH are quite comparable. Despite lower extractable K, Coorg soils produced nearly twice as much cardamom yield as compared to Idukki soils (Table 5). The leaf K vs. NH_4OAc extractable K correlations in both regions showed inconsistent patterns. For the pooled data pertaining to both regions, the r value was low and non-significant (Table 4). These observations imply that K fertilizer recommendations based on routine soil testing are unreliable for cardamom production. On the other hand, the multiple correlation between leaf K vs. NH_4OAc extractable K along with K buffer power data showed that the r value increased from a non-significant value of 0.2510 (without K buffer power integration) to a very highly significant (0.1% confidence level) value of 0.4367*** with K buffer power integration (Table 5). The coefficient of determination increased from 6.3% without K buffer power integration to 19.1% with K buffer power integration. In absolute terms, nearly 44% of the variation in leaf K is explained by the K buffer power. In relative terms, more than three-fold variation in leaf K is accounted for by the combined effect of NH_4OAc extractable K and the K buffer power the latter representing the ability of the soils to replenish K in the bulk soil solution.

DISCUSSION

Since K is principally transported by diffusion, the flux into the root must depend on the K concentration gradient between the root surface and the bulk soil solution. Root radius, root absorbing power, and the mean K concentration in the soil solution at the root surface and the effective diffusion coefficient influence the K flux. Since the K buffer power will crucially affect the mean K concentration in the soil solution at the root surface (Nair, 1996), its precise quantification might provide a more reliable index of K availability than the routine soil test with NH_4OAc. A root growing into soil will at first encounter a relatively high K concentration at

TABLE 5. Multiple correlation coefficient between cardamom yield [capsule yield in kg ha^{-1} (Y)] and soil test K data [NH_4OAc extractable K in mg kg^{-1} soil (x)] and K buffer power (z).[a]

Multiple correlation	Correlation coefficient (r)	
	A	B
Y = a + bx + cz	0.2510	0.4367***
Cardamom yield	Coorg	Idukki
	155	80

[a]A=without K buffer power integration; B=with K buffer power integration; b, c=constants for the equation; ***=significant at 0.1% confidence level.

its surface, which will be more or less equal to the K concentration of the bulk soil solution. Following root uptake, a depletion of K concentration in the soil solution at the root surface will occur. This depletion will not only depend on the net uptake of K by the root, but also on the K buffer of the soil. In poorly K buffered soil, the K concentration at the root surface may decline rapidly and the opposite takes place in soils with high K buffer power (Claassen et al., 1981). Because of this, the actual K uptake by roots is dependent on both K concentration in the soil solution and also its K buffer power. The optimum K concentration in the bulk soil solution may be lower the higher the K buffer power (Mengel and Busch, 1982). The above reasoning clearly explains results in Table 5 which have shown a remarkable improvement in the correlation coefficient when K buffer power data were integrated into the computations as opposed to its exclusion.

Cardamom yield showed a two-fold increase in Coorg soils as compared to Idukki soils. The key to this difference lies in their widely varying K buffer power and not the routine soil test K data. Both NH_4OAc extractable and HNO_3 extractable K were much less in Coorg soils when compared to Idukki soils (Table 1). However, Coorg soils showed almost a two-fold increase in their K buffer power as compared to Idukki soils as indicated by the b values in the regression functions (Table 2). On the basis of the original K buffer power concept put forth by Mengel and Kirkby (1982), this, in effect, would mean that for an identical quantity of K removed from both soils, a similar decrease in K quantity (as represented by HNO_3 extraction in this investigation) results; but the consequent reduction in K intensity (as represented by NH_4OAc extraction in this investigation) in Coorg soils would only be half as compared to the Idukki soils, implying that depletion of K in the latter will be at a much faster rate as compared to the former.

It is this inherent difference which results in the Coorg soils sustaining the cardamom yield at a much higher level. A critical examination of the r values in Table 2 indicated that more than 73% of the variation in K intensity could be explained by the procedure adopted in this investigation in Coorg soils as compared to only 34% in Idukki soils. This finding additionally supports the contention that sound K fertilizer recommendation for cardamom will need to be based on the soil's K buffer power and not exclusively on routine soil test K data.

Though the importance of K buffer power has been recognized quite early (Barrow, 1966; Mengel, 1978), substantive evidence of its crucial influence on K uptake has gathered momentum only recently (Mengel, 1985; Mengel and Busch, 1982; Mengel and Kirkby, 1982; Silberbush and Barber, 1984; Kovar and Barber, 1990; Mengel and Uhlenbecker, 1993; Meyer and Jungk, 1993). However, it must be pointed out that all of these researches refer to short-term uptake studies employing container culture and/or field grown annual crops and there is yet no reference to cardamom which is a very long duration crop. As indicated in the introduction section of this paper, cardamom is one of the world's most valuable spice crops and the economy of many countries on the Asian, African, and Latin American continents is intimately linked to its production. India is a case in point (Sadanandan, 1994). If the cost of production has to be kept within reasonable limits, as has recently been warranted by the Indian experience, a re-orientation of the K fertilizer schedule is inevitable. The buffer power concept appears to provide this re-orientation.

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