Distribution and Variation of Potassium in Black Soil at Different Stages of Crop Growth in Maize (Zea mays)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

ABSTRACT

Potassium (K) is the third most important major plant nutrient with numerous functions. The availability of K depends on concentration relative to that of Ca2+ and Mg2+ than on the total quantity of K present. The level of extraction of K by different extractants followed the order: boiling HNO3 (1 M) > Non-exchangeable K > Exchangeable K > Water soluble K. The amount of K extracted by different extractants was more in non-calcareous soil followed by calcareous soil. To know the K availability in both the soils, a pot culture experiment was conducted with the two soils (i.e., calcareous and non-calcareous) to know the response of maize to K application. Results showed that a significant higher value of available K in calcareous soil under potassium @ 120 kg K2O ha−1 treatment followed by 80 kg K2O ha−1 in non-calcareous soil irrespective of critical growth stages of hybrid maize. Among the K fractions, water soluble K was the least in magnitude and lattice K was found to be dominant one. Application of 120 kg K2O ha−1 recorded the highest potassium in all the K fractions (water soluble K, exchangeable K and nitric acid soluble K) in all stages of crop growth in calcareous soil whereas in non-calcareous soil 80 kg K2O ha−1 recorded high in all the fractions and the results emphasizing the importance of potassium in soil. Grain and straw yield of hybrid maize were significantly higher under 120 kg K2O ha−1 in calcareous soil and 80 kg K2O ha−1 in non-calcareous soil.
calcaneous soil which is well evidenced by a yield increase of 37.7% over control. A significant and positive correlation was existing between all fractions of potassium viz., \( \text{HNO}_3 \) soluble K, non-exchangeable K, exchangeable K, water soluble K and available K with grain and stover yield in calcaneous soil and non-calcareous soil. It was found that calcaneous soil showed comparatively better response to the application of potassium especially in water soluble K with an \( R^2 \) value of 0.917** followed by \( \text{HNO}_3 \) soluble K with a \( R^2 \) value of 0.895**. Therefore, the present investigation stresses the vital importance of inclusion of higher dose of potassium in calcaneous soil for maintaining soil K dynamics and enhancing yield of hybrid maize so as to sustain soil productivity.

Keywords: Potassium; potassium fractions; yield; K uptake; correlation.

1. INTRODUCTION

Potassium (K) is known as quality element and required by plants for healthy growth, but Indian agriculture has traditionally relied on the native soil resource of potassium [1]. Potassium is probably the most pertinent nutrient that has the potential of significantly affecting agricultural production in the country [2]. Historically, low application rates of K in crop have led to over-dependence on the native soil reserve K. Potassium (K), constituting an average of 1.9% of the earth’s crust and it is one of the essential macro elements required for growth and development of plants. Potassium increases the protein content of plants, the starch content in grains and tubers, vitamin C and the solid soluble contents in fruits. The crucial importance of K in quality formation confirms its role in promoting the production of photosynthates and their transport to storage organs such as fruits, grains, and tubers and enhancing their conversion into starch, protein, vitamins, and oil [3]. In general, response of crop to applied potassium is very low due to high potassium content of soils derived from basaltic parent material. However, available data in recent years indicate that the magnitude of crop response to potassium in these soils is increasing in areas of higher cropping intensity [4].

Soil K exists in four different forms viz., water soluble-K, most frequently available form to plants; exchangeable-K, held by negative charges on soil colloids and is readily available to plants; non-exchangeable or fixed-K, which is trapped between layers of expanding lattice [5]. There is a dynamic equilibrium among different forms of soil potassium and any depletion in a given form would shift the equilibrium in the direction to replenish it [6]. Higher yields and crop quality can be obtained at optimal N: K nutritional ratios.

Continued cropping without adequate application of K leads to depletion of all forms of K [7]. This will adversely affect the K dynamics and may cause constraint for crop production. Due to predominance of kaolinitic clay minerals which cannot fix K and also have low CEC, red and lateritic soils normally have the lowest amounts of all the forms of K [8]. It is evident that in spite of having comparable total K content, K supplying capacity of different soils may vary depending upon the distribution of the different forms of K. Maize is a heavy feeder, of calcium, magnesium and potassium. Presence of one of these elements in large quantities can affect the uptake of other. Relative abundance of different forms of soil K determines the K supplying capacity and K availability to crops. Keeping this in view, the present investigation was undertaken to study the distribution and dynamics of K in calcaneous soil and the relationships among different forms of K.

2. MATERIALS AND METHODS

A pot culture experiment was conducted during 2017-2018 in Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore with two types of soil viz., Black calcaneous and non-calcareous. The black calcaneous soil was taken from Eastern block, TNAU, Coimbatore and it belongs to Periyanaickenpalayam series, taxonomically referred as sandy clay loam, mixed black calcaneous Vertic Ustropept and non-calcareous soil was taken from farmers field of Ikkarai Boluvampatti village, Thondamuthur block, Coimbatore district of Tamil Nadu and it belongs to Noyyal series, taxonomically referred as fine-loamy, mixed, isohyperthermic, Typic Haplustalf. In each pot, one maize plant (CO 6 variety) was maintained at required level of soil moisture.

In calcaneous soil, the initial status was found to be medium in organic carbon, low in available N, medium in available P and high in available K status. Among the micronutrients, DTPA Mn found to be sufficient and Fe, Zn and Cu were...
deficient in calcareous soil ($S_1$). In non-calcereous soil ($S_2$), the initial status found to be medium in organic carbon, low in available N, high in available P and high in available K status. The K fractions viz., water soluble K, exchangeable K, non-exchangeable K and HNO$_3$ soluble K details were furnished in the Table 1. There were four treatments each replicated thrice in Completely Randomized Block Design. Based on STCR recommendation, the recommended dose of N, P$_2$O$_5$ and graded levels of K were applied. K$_2$O levels were fixed based on 100% STCR K, 125% STCR K and 150% STCR K which worked out to be 40 kg K$_2$O ha$^{-1}$ ($T_3$), 80 kg K$_2$O ha$^{-1}$ ($T_3$) and 120 kg K$_2$O ha$^{-1}$ ($T_4$) applied in both the soils. Grain yield target of 10 t ha$^{-1}$ was fixed to arrive the 100% STCR-K. The sources of N, P and K used were urea, single super phosphate (SSP) and muriate of potash (MOP).

| Parameters                | Calcereous soil ($S_1$) | Non-calcereous soil ($S_2$) |
|---------------------------|------------------------|-----------------------------|
| pH                        | 8.47                   | 7.91                        |
| EC (dS m$^{-1}$)          | 0.47                   | 0.34                        |
| OC (g kg$^{-1}$)          | 5.20                   | 5.25                        |
| Free CaCO$_3$ (%)         | 12.5                   | 0.50                        |
| K fractions (mg kg$^{-1}$) |                        |                             |
| Water soluble K           | 15.7                   | 20.0                        |
| Exchangeable K            | 355                    | 375                         |
| Available K               | 741                    | 790                         |
| Non-exchangeable K        | 392                    | 575                         |
| HNO$_3$ soluble K         | 752                    | 950                         |
| Total K                   | 12975                  | 13574                       |

AFN = 4.01 T - 0.76 SN - 0.83 ON
FP$_2$O$_5$ = 1.57 T - 2.71 SP - 0.61 OP
FK$_2$O = 2.09 T - 0.26 SK - 0.65 OK

Chart 1. STCR based fertilizer prescription equations for maize

Where, FN, FP$_2$O$_5$ and K$_2$O are fertilizer N, P$_2$O$_5$ and K$_2$O in kg ha$^{-1}$, respectively; T is the yield target in q ha$^{-1}$; SN, SP and SK are soil available N, P and K in kg ha$^{-1}$, respectively and ON, OP and OK are the quantities of N, P and K in kg ha$^{-1}$ supplied through FYM, respectively.

The soil samples were collected periodically at vegetative, tasseling and harvest stages of maize for chemical analysis. The dried samples were analyzed for K parameters (water soluble K, exchangeable K, non-exchangeable K and nitric acid soluble K). For determination of water soluble-K, exchangeable-K and non-exchangeable-K, procedures given by [9], [10], [11] were followed, respectively. The potassium content of the extract was determined using flame photometer.

3. RESULTS AND DISCUSSION

3.1 Water Soluble K

The water soluble-K content was found to be significantly affected by potassium application. In calcareous soil ($S_1$) and non-calcereous soil ($S_2$), the water-soluble K varied from 10.3 to 12.6 and 17.1 to 18.1 ppm (vegetative), 8.90 to 11.2 and 14.6 to 18.0 ppm (tasseling) and 6.25 to 8.77 and 10.4 to 12.1 ppm (harvest), respectively (Table 2). It was observed that with the increase in potassium levels, the water soluble K content also increased significantly and showed decreasing trend from vegetative to harvest stages of maize in both the soil types. Non-calcereous soil recorded the higher water-soluble K in all the three stages of crop growth indicating the capability of the non-calcereous soil to release higher water-soluble K in all the stages of crop growth than calcareous soil. Application of potassium @ 120 kg K$_2$O ha$^{-1}$ resulted in higher water-soluble K in calcareous soil ($S_1$) which was on par with potassium @ 80 kg K$_2$O ha$^{-1}$ in non-calcereous soil ($S_2$). The potassium application increased the water-soluble K content significantly over control in all the treatment combinations. The continuous application of water-soluble potassic fertilizers [12] would have increased the concentration of K in soil solution with the increase in the rate of K application [13].
Table 2. Effect of different levels of potassium on water soluble and Exchangeable K (ppm) at different stages of maize

| DAI/ Treatments   | Water-soluble K | Exchangeable K |
|-------------------|-----------------|----------------|
|                   | Vegetative S1   | Tasseling S1  | Harvest S1 |
|                   | S2   | Mean | S1 | S2 | Mean | S1 | S2 | Mean | S1 | S2 | Mean |
| T1 – Control      | 10.3 | 17.1 | 13.7 | 8.90 | 14.6 | 11.8 | 6.25 | 10.4 | 8.30 | 341 | 362 | 352 |
| T2 – 40 kg K2O ha⁻¹ | 11.3 | 17.5 | 14.4 | 10.1 | 15.3 | 12.7 | 7.42 | 11.3 | 9.40 | 356 | 370 | 363 |
| T3 – 80 kg K2O ha⁻¹ | 12.2 | 17.8 | 15.0 | 10.9 | 15.8 | 13.3 | 8.36 | 11.7 | 10.0 | 362 | 375 | 368 |
| T4 – 120 kg K2O ha⁻¹ | 12.6 | 18.1 | 15.4 | 11.2 | 16.0 | 13.6 | 8.77 | 12.1 | 10.4 | 366 | 378 | 372 |
| Mean              | 11.6 | 17.6 | 14.6 | 10.3 | 15.4 | 12.9 | 7.71 | 11.4 | 9.50 | 356 | 371 | 364 |
| S / T / SXT / S  | SXT / T / SXT  | SXT / T / SXT | SXT / T / SXT |
| SED (P=0.05)      | 0.32 | 0.45 | NS  | 0.35 | 0.50 | NS  | 0.20 | 0.29 | NS  | 6.24 | 8.82 | NS  |

Table 3. Effect of different levels of potassium on HNO₃ soluble and Non-Exchangeable K (ppm) at different stages of maize

| DAI/ Treatments   | HNO₃ soluble K (ppm) | Non- Exchangeable K |
|-------------------|----------------------|---------------------|
|                   | Vegetative S1        | Tasseling S1        | Harvest S1 |
|                   | S2   | Mean | S1 | S2 | Mean | S1 | S2 | Mean | S1 | S2 | Mean |
| T1 – Control      | 732 | 864 | 798 | 667 | 815 | 741 | 648 | 795 | 721 | 391 | 501 | 446 |
| T2 – 40 kg K2O ha⁻¹ | 754 | 884 | 819 | 704 | 833 | 769 | 684 | 814 | 749 | 398 | 514 | 456 |
| T3 – 80 kg K2O ha⁻¹ | 773 | 901 | 837 | 732 | 850 | 791 | 706 | 830 | 768 | 411 | 526 | 469 |
| T4 – 120 kg K2O ha⁻¹ | 783 | 912 | 847 | 748 | 864 | 806 | 717 | 841 | 779 | 417 | 534 | 475 |
| Mean              | 760 | 890 | 825 | 713 | 841 | 777 | 689 | 820 | 754 | 404 | 519 | 462 |
| S / T / SXT / S  | SXT / T / SXT  | SXT / T / SXT  | SXT / T / SXT |
| SED (P=0.05)      | 6.56 | 9.28 | 13.1 | 7.17 | 10.1 | 14.33 | 8.21 | 11.6 | 16.4 | 4.00 | 5.66 | 8.01 |
| CD (P=0.05)       | 13.9 | 19.6 | NS  | 15.1 | 21.4 | NS  | 17.4 | 24.6 | NS  | 8.49 | 12.0 | NS  |

Table 4. Correlation among K fractions, stover and grain yield of maize in black soil

| K fractions                  | Calcareous soil (S1) | Non- calcareous soil (S2) |
|------------------------------|----------------------|---------------------------|
|                              | Grain yield (g plant⁻¹) | Stover yield (g plant⁻¹) | Grain yield (g plant⁻¹) | Stover yield (g plant⁻¹) |
| HNO₃ soluble K (mg kg⁻¹)      | 0.895**               | 0.880**                   | 0.517**                 | 0.478*                   |
| Non- exchangeable K (mg kg⁻¹) | 0.854**               | 0.836**                   | 0.281*                  | 0.448**                  |
| Exchangeable K (mg kg⁻¹)      | 0.775**               | 0.748**                   | 0.372*                  | 0.529*                   |
| Water soluble K (mg kg⁻¹)     | 0.917**               | 0.902**                   | 0.734**                 | 0.786**                  |
3.2 Exchangeable-K

In both the soil types (S$_1$ and S$_2$), K application has increased the exchangeable-K content over control at all the stages of crop growth. The exchangeable K content showed continuous reduction from vegetative, tasseling and harvest stages of maize with a mean varied from 352 to 372 ppm at vegetative, 345 to 365 ppm at tasseling and 333 to 361 ppm at harvest stages, respectively (Table 2). Application of 120 kg K$_2$O ha$^{-1}$ registered the higher amount of exchangeable K at vegetative (366 and 378 ppm), tasseling (356 and 374 ppm) and harvest stages (352 and 370 ppm) of maize in calcareous soil (S$_1$) and non-calcareous soil (S$_2$). Application of potassium @ 120 kg K$_2$O ha$^{-1}$ is necessary to get higher exchangeable K in calcareous soil whereas in non calcareous soil (S2), application of potassium @ 80 kg K$_2$O ha$^{-1}$ showed on par effect with each other (Table 2). This is due to shift in equilibrium by addition of water soluble K sources in both the soil types [14]. As in case of water-soluble K, withholding K from schedule resulted in a reduction in exchangeable K content [13].

3.3 HNO$_3$ Soluble K

Among all the K fractions investigated, HNO$_3$ K fraction constitutes about more than 80 % of the total K in soils (S$_1$ and S$_2$) with mean value ranged from 732 to 783 and 864 to 912 ppm (vegetative), 667 to 748 and 815 to 864 ppm (tasseling) and 648 to 717 and 795 to 841 ppm (harvest) in calcareous and non-calcareous soil, respectively. The mean values varied from 798 to 847 in vegetative stage, 741 to 806 ppm at tasseling, 721 to 779 ppm at harvest stage, respectively (Table 3). The amount of lattice K mainly depends on clay mineralogical composition of soil rather than the dynamics among different K pools. The lower amount of lattice K in the absence of K fertilization slower shift in equilibrium to compensate crop removal and to translocation of clays as reported [15]. Among all the extractants, significantly higher amounts of K were extracted by 1 N HNO$_3$ because in addition to exchangeable K, some of the non-exchangeable K is brought into solution by the breakdown of primary and secondary clay minerals. The mineral acids release more K than organic acids since mineral acids add higher H$^+$ activity for the same concentration and are obviously more effective in solubilizing K from minerals [16].

3.4 Non-Exchangeable-K (NEK)

The data indicated that maximum non-exchangeable K content values were observed with the application of potassium @ 120 kg K$_2$O ha$^{-1}$ treatment at all the stages of crop sequence in calcareous soil (S$_1$) which was on par with potassium @ 80 kg K$_2$O ha$^{-1}$ in non-calcareous soil. The non-exchangeable K values were 391 to 417 and 501 to 534 ppm, 337 to 392 and 457 to 491 ppm, 327 to 365 ppm and 449 to 472 ppm at vegetative, tasseling and harvest of maize in calcareous soil and non-calcareous soil, respectively (Table 3). It indicated that with the increase in native lime levels, the non-exchangeable K content decreased significantly. The higher status of non-exchangeable K in some soil series might be due to higher pedo-chemical weathering of K bearing minerals in soil and transformation into illite and vermiculite [1]. It indicated that non-exchangeable K was released and contributed partially to the soil [17].

3.5 Stover and Grain Yield

The economic biomass in terms of grain yield and stover yield of hybrid maize increased significantly by the application of different levels of potassium. The grain and stover yield varied from 35.0 to 62.2 g plant$^{-1}$ and 56.0 to 73.6 g plant$^{-1}$ in calcareous soil (S$_1$), whereas in non-calcareous soil (S$_2$), it ranged from 48.0 to 66.9 g plant$^{-1}$ and 77.1 to 106 g plant$^{-1}$, respectively (Fig. 1). Progressive increase in grain yield and stover yield was observed with application of graded levels of K addition from 40 kg K$_2$O to 120 kg K$_2$O in calcareous and non-calcareous soil (Fig. 1). The straw yield of hybrid maize followed similar trend to that of grain yield. Therefore, the availability of K during initial stage to until the end of grain filling increases the filled grain number in cob and grain weight, as observed in these studies. Increasing in stover yield may be attributed to increase in plant height and dry matter production [18]. The positive effect of K on crop yield might also be due to its requirement in carbohydrate synthesis and translocation of photosynthesis and also may be due to improved yield attributing characters, shoot growth and nodulation [4]. Application of potassium as found to increase the shoot dry weight of maize may be due to selective an adequate potassium uptake in plant tissue. This yield increase was mainly due to significant improvement in the yield attributes due to balanced supply of nutrients. Similar findings were also reported [2], [19], [20].
3.6 Potassium Uptake

The K content in grain and stover of maize increased progressively and significantly with increased K application rates. The result indicated a marked variation in the K uptake by hybrid maize due to the variation in fertilizer treatments imposed in both the soils. Maximum total K uptake (1.48 and 1.73 g plant⁻¹) as recorded with the treatment receiving 120 kg K₂O ha⁻¹ in calcareous and non-calcareous soils, respectively which differed significantly when compared to all other treatments. In calcareous soil, potassium @ 120 kg ha⁻¹ is necessary for higher K uptake whereas in non-calcareous soil, potassium @ 80 kg ha⁻¹ it showed on par effect with application of 120 kg K₂O ha⁻¹ (Fig. 2). In general, the K uptake was increased with crop growth and maturity of the crop [20]. The highest total K uptake was due to higher available K status and high cation exchange capacity in the initial soil. Plants deficient in potassium will not produce proteins despite an abundance of available nitrogen. Instead, incomplete proteins such as amino acids, amides and nitrates will accumulate in the cell. This is because of the enzyme nitrate reductase, which catalyzes the formation of proteins, is activated by potassium [21]. Similar to the present study on maize crop, increase in uptake due to increased levels of potassium was noticed [22], which was attributed to translocation of nutrients by applied K which plays a role in increasing nutrients uptake by plants. Potassium has a synergetic effect on
uptake of nitrogen and other nutrients due to which all the treatments applied with potassium was superior to control [23],[4].

3.7 Relationship between K Fractions, Crop Yield and Nutrient Uptake

A significant and positive correlation was existing between all fractions of potassium viz., HNO₃ soluble K, non-exchangeable K, Exchangeable K and water-soluble K with grain and stover yield in calcareous soil (S₁) and non-calcareous soil (S₂). Calcareous soil showed comparatively better response to the application of potassium especially in water soluble K with an R² value of 0.917** followed by HNO₃ soluble K with an R² value of 0.895** (Table 4). Increase in uptake of K with increase in levels of K application on calcareous and non-calcareous soils in the present studies implies that inadequate supply or absence of any one major nutrient to the crop would result in imbalance supply of other nutrient elements and consequent reduction in yield, nutrient use efficiency and uptake [24]. All the forms of K showed a positive trend of correlation among themselves largely corroborating the well-known concept of existence of a dynamic equilibrium among different forms of K present in soil through which K supply to the roots of crop plants are directly or indirectly ensured. Similar results were also reported [25], [16] by which provide credence to the results obtained in the study.

4. CONCLUSIONS

The results indicated that the amount of K extracted by different extractants was more in non-calcareous soil followed by calcareous soil. Significant higher available K in calcareous soil with the application of enhanced K application (120 kg K₂O ha⁻¹) was observed and the effect was on par with the application of lesser K application (80 kg K₂O ha⁻¹) in non-calcareous soil. Higher levels of application of K led to higher values of K fractions during of crop growth stages, emphasizing the importance of potassium to calcareous soil. Similarly, significantly higher grain and straw yield of hybrid maize recorded at higher level of K (120 kg K₂O ha⁻¹) in calcareous soil than slightly lower level of K (80 kg K₂O ha⁻¹) to non-calcareous soil. Also, there is a significant and positive correlation was existing between fractions of potassium with grain and stover yield. The present investigation concludes that there is a vital importance for inclusion of higher dose of potassium in calcareous soil for maintaining soil K dynamics and enhancing yield of hybrid maize and sustain soil productivity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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