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# Spatial variability of cotton potassium nutrition in relation to soil cations in agricultural fields

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## Abstract

The adequacy of potassium (K) in plants is influenced not only by the amount of extractable K in the soil, but also by the presence and balance of other essential cations such as magnesium (Mg) and calcium (Ca). However, Mg and Ca are often overlooked in soil fertility assessments. Therefore, this research aimed to investigate K availability in cotton-growing agricultural soils, examine potential K deficiencies induced by high Mg and Ca levels, and map their spatial distribution. The research was conducted in the Amik Plain of Hatay Province, located in the easternmost part of Türkiye's Mediterranean region. Ammonium acetate extraction for soils and wet digestion for plant tissues were used to determine K, Ca, and Mg contents. Relationships between soil and plant parameters were analyzed using Pearson's correlation, while spatial trends of potassium deficiency linked to high Ca and Mg were modeled through Kriging interpolation. The results revealed that soil Ca and Mg levels were considerably higher than K, which adversely affected plant K uptake. K/Mg and K/Ca ratios in soil were found to range between 0.04–1.02 and 0.02–0.14, respectively. Leaf K concentrations varied between 0.47% and 3.25%, indicating widespread K deficiency. Contrary to the common assumption that soils rich in K do not cause deficiency, the findings showed that 57.1% of cotton plants grown in K-rich soils exhibited hidden K deficiency. Therefore, K/Ca, K/Mg, and K/(Ca+Mg) ratios should be considered when evaluating K availability in soils with high extractable K.

**Keywords:** Amik Plain, hidden hunger, Kriging, K/Ca ratio, K/Mg ratio, sources of K deficiency.

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## Introduction

Potassium (K) in the soil is formed as a result of the dispersion and breakdown of rocks containing K minerals, such as K feldspars (orthoclase and microcline) and micas (muscovite and biotite). It is also found in the soil as a secondary or clay mineral. K increases the resistance of plants to drought by maintaining the water balance. It has positive effects on overcoming summer drought and frost resistance. K also increases the resistance of plants to diseases. It ensures the maturation of the seed and the development of the plant's root system. In plants that uptake sufficient K, water loss due to transpiration decreases (Kacar and Katkat, 2010).

Plants uptake K from the environment in which they grow in the form of the $K^+$ cation. Although K uptake is higher than other nutrients, except nitrogen (N), the use of K fertilizers is very rare. This is due to research conducted years ago, which led to the belief that the soils of Türkiye are generally rich in K (about 85%, Eyüpoğlu, 1999; Sönmez et al., 2018), a belief that persists today. Another significant reason is that agricultural soils are often fertilized without determining their specific fertilizer requirements. The most commonly used fertilizers by farmers in Türkiye are urea (46-0-0), diammonium phosphate (DAP) (18-46-0), 20-20-0 (compound fertilizer), and ammonium sulfate (21-0-0) (Anonymous 1, 2024). Anthropogenic

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factors and farming practices cause changes in the nutrient content of agricultural soils. Haileselassie et al. (2011) reported that continuous application of nitrogen and phosphorus (P) fertilizers can cause a deficiency of K, Mg, Ca, sulfur (S), and microelements in soil. If K continues to be excluded from fertilizer programs in agricultural practices, the risk of K deficiency may increase.

Recent studies indicate a growing incidence of potassium (K) deficiency in various regions of Türkiye. Yalçın and Çimrin (2021) found K deficiency in 23.33% of the soils in the Kırıkhan–Reyhanlı region of Hatay province. Yalçın et al. (2018) discovered it in 28.75% of the meadow–pasture soils of the same region, while Yayla (2008) warned that the absence of K fertilization in Tokat Kazova soils could lead to low yields due to low potassium levels. In a study conducted to determine the mineral nutrition level of citrus orchards in three provinces (Adana, Mersin, and Hatay) in the Çukurova Region, a serious deficiency (72.3%) was found in terms of K nutrition, especially in Hatay province. In contrast, no samples were found to be "insufficient" in Mg (Torun et al., 2005).

The K deficiency found in various studies may also be due to the high Ca and/or Mg levels in these regions. An overabundance of a specific cation in soil can frequently hinder the uptake and availability of other essential cations to plants (Hoskins, 1997). For instance, when Mg and/or Ca are present at disproportionately higher levels than potassium (K) in the soil exchange complex, the accessibility of K to plants may decrease, potentially leading to deficiency. Therefore, evaluating K sufficiency requires considering not only the absolute K concentration but also its balance relative to other major cations such as Mg and Ca. For this reason, information about the proportional levels of competing cations (Mg, Ca) should be obtained rather than focusing on a single cation (e.g., "K"). Nutrient antagonism should be investigated (Laekemariam et al., 2018), and leaf analysis should be performed in addition to soil analysis.

Due to the antagonistic interaction among Mg, K, and Ca, elevated grades of any of these elements in the soil may reduce the uptake of the others by plants, even when present in sufficient quantities. This phenomenon has been reported by numerous researchers (Gosnell and Long, 1971; Marschner, 1995; Garcia et al., 1999). Some studies have also documented that potassium uptake decreases in soils with high Ca and Mg concentrations (Donaldson et al., 1990; Kingston et al., 2009; Meyer, 2013).

In the current study, the hypothesis that there may be K deficiency due to Mg and Ca, which have higher concentrations than K, was investigated in the Amik Plain soils of Hatay, Türkiye where intensive agriculture is carried out.

The aims of our research were to assess plant-available K concentrations in cotton-growing soils, evaluate K deficiencies resulting from excess Mg and Ca-induced, analyze their spatial variabilities, and create a potassium status map for the region.

## Material and Methods

### Description of the study area

The study area, in Hatay province of Türkiye, 36°13'04" – 36°29'55" N; It is the Amik Plain located at latitude and longitude 36°11'37" – 36°14'59" E (Figure 1). Amik Plain, one of the largest plains in Türkiye, covers an area of 105387 hectares (Aytop, 2022). Cotton, wheat, corn, onion, vegetables and fruits are intensively cultivated in the plain (Korkmaz, 2009). The Amik Plain, which has a Mediterranean climate, has an annual average temperature of 18 °C, an annual average evaporation of 1877 mm, and an annual rainfall of 1124 mm (long-years) (Kılıç, 2011). In 2015, when the sampling was done, the average annual temperature was 18.5 °C and the average annual precipitation was 103.8 mm (Anonymous 2, 2016). However, excessive fertilization and spraying are carried out (Baba and Atay, 2019). The dominant parent material in the plain is alluvial deposit and Vertisol soils are the majority (32.7%). On average, two crops are grown per year (Kılıç, 2011).

### Sampling, preparation of samples and analyses

Samples were collected from farmlands where cotton (*Gossypium hirsutum* L.) was grown. Therefore, the sampling distance was not taken into account. It was taken randomly. Leaf samples were also collected from the fields where soil samples were taken. The location of the samples was recorded using a Magellan Explorist 610 brand GPS (Geographical Positioning System). Four samples were collected from the soil sampling point and these were mixed into a single sample. A total of 154 samples were collected from 0-20 cm depth.

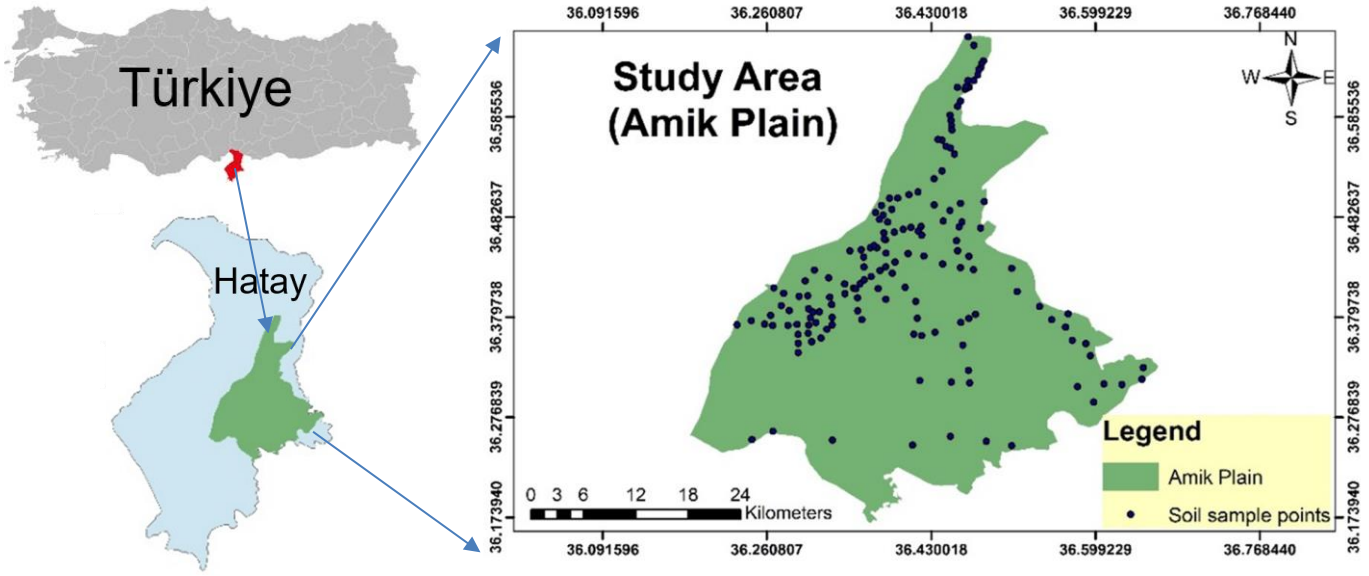



Figure 1. Locations of soil and leaf sampling points in the study area

The soil samples brought to the soil preparation room were laid in drying containers, and the granules and twig pieces cleaned and left to dry. The dried soil samples were pounded with wooden mallets and sieved through a 2 mm sieve and prepared for analysis. In the soil samples prepared for analysis, extractable K, Mg and Ca contents (mg $kg^{-1}$) were determined by measuring with Agilent 5100 brand ICP-OES device according to ammonium acetate method (1N $NH_4AOc$, pH=7.0) (Richards, 1954). The textures of the research area soils were determined according to Bouyoucos (1951). In addition, pH in saturated sludge (Richards, 1954), texture according to Bouyoucos hydrometer method and volumetric lime in Scheibler calcimeter were determined (Klute, 1986). The classifications of soil pH and lime amounts were made as reported by Ülgen and Yurtsever (1995); and the classifications of K, Ca and Mg concentrations were made as reported by the Food and Agriculture Organization (FAO, 1980).

Leaf specimens were collected from the youngest newly matured leaves on the caulis during full flowering (Samuels et al., 1959). Fifteen leaves were collected from each sample point (154 points). The collected leaf samples were brought to the laboratory without waiting, numbered and cleaned. It was then treated with 0.1 N HCl solution and washed with distilled water. The washed leaves were loosely arranged and left to dry in the drying cabinet at 65°C until their weight was constant (approximately 48 hours).

0.30 g was taken from the ground plant parts and analyzed according to the wet digestion method in a pressure microwave oven with 0.5 ml nitric acid ($HNO_3$, d= 1.42) and 2 ml hydrogen peroxide ($H_2O_2$, 30%) as recommended by Miller (1998). After digestion, the samples were filtered and the amounts of K, Ca and Mg were determined in the Agilent 5100 brand ICP-OES device. The nutrient sufficiency class of Jones et al. (1991) was used for leaves.

**Statistical Analysis**

IBM-Statistical Package for Social Sciences (SPSS) 26.0 software package were used for descriptive statistical analysis of extractable K, Mg, Ca, K/Mg and K/Ca data (Table 1). Coefficient of variation (CV); rated as low (< 20%), medium (20–50%), and highly variable (> 50%) (Laekemariam et al., 2018).

Table 1. Descriptive statistics of soil parameters in the study area (n= 154)

| | Range | Minimum | Maximum | Mean | Std. Deviation | CV | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|---|
| pH | 1.55 | 7.05 | 8.60 | 7.62 | 0.29802 | 3.91 | 0.566 | 0.270 |
| Lime (%) | 37.07 | 0.82 | 37.89 | 18.86 | 11.42023 | 60.54 | -0.226 | -1.349 |
| K (mg $kg^{-1}$) | 932 | 77 | 1009 | 289.13 | 139.997 | 48.42 | 1.746 | 5.579 |
| Mg (mg $kg^{-1}$) | 2281 | 414 | 2695 | 1353.30 | 446.919 | 33.02 | 0.669 | 0.528 |
| Ca (mg $kg^{-1}$) | 7407 | 1559 | 8966 | 5077.34 | 1197.020 | 23.58 | 0.513 | 1.672 |
| K/Mg | 0.98 | 0.04 | 1.02 | 0.25 | 0.17041 | 69.64 | 2.284 | 6.334 |
| K/Ca | 0.12 | 0.02 | 0.14 | 0.06 | 0.02155 | 38.01 | 0.958 | 1.673 |
| K (Plant, %) | 2.78 | 0.47 | 3.25 | 1.4 | 0.46226 | 32.15 | 0.523 | 0.681 |

Std.: Standart, CV: Coefficient of variation

### Geostatistical analysis and mapping

The most appropriate and reliable maps in soil-related studies are drawn using kriging. In this research, ordinary kriging (OK), simple kriging (SK), and universal kriging (UK) were used to interpolate the values of unsampled locations and produce optimal maps showing the plant-available K status in the land. Kriging, unlike other forecasting methods, examines the uncertainty or error in the forecast field. In the present study, the root mean square error (RMSE) was used to determine and evaluate the best interpolation model (Table 2). The lowest RMSE values give the most accurate estimate (Aytop et al., 2023). The following equation was used for the RMSE values.

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}[Z(Xi)-\check{Z}(Xi)]^2}$$

In this formula, n: number of observations, Z(Xi): predicted value Ž(Xi): observed value. As the map projection, Universal Transverse Mercator (UTM) Zone 37 N projection and WGS_1984 Datum were used. ArcGIS 10.7.1 was used for spatial distribution maps of the investigated soil properties (Figure 4).

Table 2. Correlations between examined parameters

| | pH | Lime | K (Soil) | Ca (Soil) | Mg (Soil) | K/Ca | K/Mg | K (Plant) |
|---|---|---|---|---|---|---|---|---|
| pH | 1 | | | | | | | |
| Lime | -0.305** | 1 | | | | | | |
| K (Soil) | | 0.181* | 1 | | | | | |
| Ca (Soil) | | 0.261** | 0.551** | 1 | | | | |
| Mg (Soil) | | -0.318** | -0.183 * | | 1 | | | |
| K/Ca | | | 0.837** | | -0.209** | 1 | | |
| K/Mg | | 0.188* | 0.841** | 0.431** | -0.554** | 0.701** | 1 | |
| K (Plant) | -0.236** | | 0.408** | | -0.171* | 0.485** | 0.348** | 1 |

**. Correlation is significant at the 0.01 level (*P*< 0.01)

*. Correlation is significant at the 0.05 level (*P*< 0.05*)*

## Results and Discussion

### Texture, pH and lime ($CaCO_3$)

77. 9% of the lands were clay–loam (C), 9. 1% were clay–loam (CL), 5. 2% were silt–clay (SiC), 2. 6% were sandy–clay–loam (SCL), 1. 9% were loam (L), 1. 9% were silt–loam (SiL), 0. 6% were sandy–clay (SC) and 0. 6% were sandy–loam (SL) texturized. The pH values of the study area lands ranged from 7.05 to 8.60 (Table 1). pH was classified as 36.4% neutral (6.50–7.50), 63.0% slightly alkaline (7.50–8.50) and 0.6% strongly alkaline (> 8.50). The amount of lime in Amik Plain, which has very calcareous soils, was found to be between 0.82–37.89% (Table 1). In the research area, 3.9% of the soils were slightly calcareous (<1), 14.9% were calcareous (1-5%), 16.2% were medium calcareous (5-15%), 25.3% were very calcareous (15-25%) and 39.6% were very calcareous (>25%).

### Extractable K, Mg and Ca

The K contents of the soils ranged from 77 and 1009 mg $kg^{-1}$ (Table 1). 3.2% of the study area lands were low (50–100 mg $kg^{-1}$), 54.6% were medium (100–300 mg $kg^{-1}$), 41.6% were good (300–1000 mg $kg^{-1}$) and 0.6% of excess (> 1000 mg $kg^{-1}$) K was determined. The Mg contents of the soils varied between 414 to 2695 mg $kg^{-1}$ (Table 1). Classification, the amounts of Mg; It was found that in 1.3% of the lands were sufficient (160–480 mg $kg^{-1}$), in 68.2% much (480–1500 mg $kg^{-1}$) and in 30.5% too much (> 1500 mg $kg^{-1}$). The Ca contents of soils ranged from 1559 to 8966 mg $kg^{-1}$ (Table 1). Ca contents were found to be sufficient (1150–3500 mg $kg^{-1}$) in 7.8% of the lands and high (3500–10000 mg $kg^{-1}$) in 92.2%. In the evaluation of the K, Mg and Ca results of the soils, the limit values determined by Pizer (1967), Loué (1968), and Sumner and Miller (1996) were used.

### K/Mg, K/Ca Ratios and K (Plant)

As can be seen from Table 1, the soils had K/Mg ratios ranging from 0.04 to 1.02 and K/Ca ratios ranged from 0.02 to 0.14. The K content of the leaves were between 0.47–3.25%. Insufficient (< 1.5%) of leaves were determined in 57.1%, sufficient (1.5–3%) in 42.2% and in 0.6% excess K (> %3). In evaluating the K results of the leaves, the limit values determined for cotton by Jones et al. (1991) were used.

### Statistical Data

When the coefficients of variation (CV) in Table 1 are examined, pH in Amik Plain soils showed low variability (< 20%). K, Mg, Ca, K/Ca and K in plant showed moderate variability (between 20%–50%), while lime and K/Mg ratio showed high variability (> 50%) (Table 1).

Soil analysis methods work according to the principle of imitating the uptake of nutrients from the soil by plants (Reuther and Smith, 1954). In the extraction processes, it is not known whether the high or low

absorption caused by the plant's need and the soil area in which the plant roots interact is fully represented. Therefore, soil analysis methods should be considered as an indicator of the availability of nutrients in soils. In order to reach a definite conclusion in terms of the nutrition of the plant, it is necessary to determine the tissue concentrations by leaf analysis. Leaf analyses are based on the concept that elemental concentrations in plant tissues may be an indicator of the availability of plant nutrients existing in soils (Tisdale et al., 1985). On the other hand, plant tissue analyses are considered as a direct method compared to soil analyses in assessing plant nutritional status, but the analysis of well-defined plant parts is absolutely necessary in this method (Hallmark and Beverly, 1991). For this reason, in order to get more accurate results from the research, cotton leaves were also collected appropriately from the same locations where soil samples were taken in this study.

Nutrient deficiency is not always caused by a lack of plant nutrients in the soil (Johansson and Hahlin, 1977; Hannan, 2011). This study determined that although there was enough K nutrient in the lands, it was insufficiently taken up by the plants (Table 1). High Mg concentration in the soil reduced the K uptake of the cotton plant. It was concluded that the reason is that Mg has a suppressive effect on K uptake. The suppressive effect of magnesium on potassium uptake is thought to result from competition for metabolically produced binding compounds. The fact that K is affected by high amounts of the nutrient element Mg is compatible with the ion uptake theory in terms of chemistry. Similarly, the inhibitory effect of very high amounts of Ca nutrients in the soil on the K uptake of the cotton plant can be explained by the fact that it causes a marked decrease in the permeability of the cells. This decrease in permeability means that the movement of K ions into the cell is suppressed. In addition, since the ion diameters and charges of K, Mg and Ca are very close to each other, the exchange surfaces of the cell may not have been able to distinguish the difference between these ions. Therefore, it make us think that Mg and Ca ions may have been arbitrarily absorbed more than the K ion by the exchange surfaces, regardless of which ion is suitable for that surface. From the obtained results, it is understood that the cations K, Mg, and Ca compete with each other, and an increase in the concentration of any of these ions may decrease the uptake of the other two ions. Ranade-Malvi (2011) also reported similar results in their studies. Adverse effects (antagonism) among nutrient elements of similar size and value can also cause plant nutrient deficiencies (Marschner, 1995).

The rate of Mg-induced K deficiency in the study area soils was 92.9%, as seen in Figure 2. Approximately 80% of these soils were clay-textured; Mg-induced K deficiency was 90.8% only in clay-textured soils. While Ca-induced K deficiency was 84.4%, this ratio is 84.2% in C-textured soils. In this case, 99.8% of Ca-induced K deficiency was in C-textured soils. K deficiency due to Ca+Mg was determined to be 100%. In the Amik Plain, where Vertisol soils are predominant, the predispositions of all textured and C textured soils to Mg, Ca, and Ca+Mg-induced K deficiency were determined as %92.9–%84.2, %85.1–%84.4, and %100–%100, respectively (Figure 2). Since the level of cations in the soil was determined as Ca> Mg> K, K deficiency was associated with excessive amounts of Ca and Mg. Calcareous lands tend to have high Ca concentrations, predominating on clay surfaces and other exchange places. When the antagonistic predispositions of cationic nutrient elements are examined, it becomes clear that Ca and Mg, in particular, tend to inhibit K uptake by competing for binding sites on root surfaces. Therefore, plants grown in lands with high lime content may show K deficiencies even if soil K levels are adequate (Havlin et al., 1999). In earlier work, Pierre and Bower (1943) observed that the high concentrations of Ca and Mg in soil solution restricted the uptake of K. When establishing these rates, Turan and Horuz (2012)'s ratios were used: K/Mg < 0.50, K/Ca < 0.077, and K/(Ca+Mg) < 0.98. Several studies have reported different K/Mg ratios in different soils when determining nutrient status. While investigating Germany's soil fertilizer requirements, Kundler et al. (1989) noted that this ratio was 2:1 in sandy soils, 1.8:1 in sandy loam soils, 1.7:1 in loam soils, 1.2:1 in clay soils, and 3.6:1 in peat soils. Loide (2001) indicated that the K/Mg ratio should be 1.2:1 in sandy soils, 1:1 in sandy loam soils and loam soils, 0.7:1 in clay soils, and 2.2:1 in peat soils.

In Table 2, correlations between some soil properties and between K in cotton leaves and some soil properties were determined. Accordingly, it was found that there were significant relationships between these features at the $P< 0.01$ and $P< 0.05$ level. The fact that there were very significant and very strong relationships between soil K and soil K/Mg ($r= 0.841^{**}$) and K/Ca ($r= 0.837^{**}$) ratios at the level of $P< 0.01$ supported that there might be potential Mg and Ca-induced K deficiency in the soils of the study area. Similarly, the presence of very significant and moderately strong relationships at the 0.01 ($P< 0.01$) level between plant K and soil K ($r= 0.408^{**}$), as well as between plant K and soil K/Mg ($r= 0.348^{**}$) and K/Ca ($r= 0.485^{**}$) ratios, also supported the possibility of potential Mg and Ca induced K deficiency in the soils of the study area.

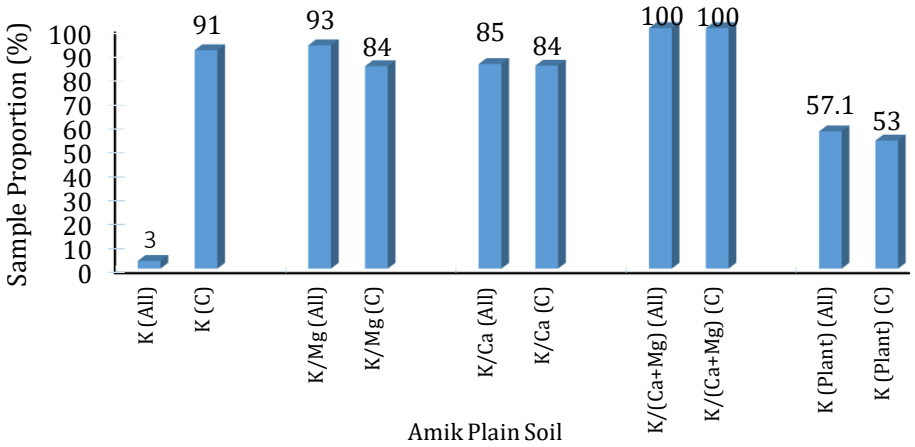



Figure 2. Rate of Ca- and Mg-induced K deficiency in the study area (All: soils of all textures; C: soils with clay texture only)

With the data obtained as a result of the analysis of cotton leaves collected from the research area, it was determined that the K in the plant was below the sufficiency limit, but it did not show visual symptoms of K deficiency. This situation strongly implied that the cotton plant had a "hidden hunger" for potassium. K fertilizer is not included in the fertilization program due to the perception among farmers that the amount of K in agricultural soils is generally sufficient and also because fertilizers are expensive. For this reason, ions such as Mg and Ca, whose concentration is higher than K in the soil solution, may have suppressed the K in the solution and prevented it from being absorbed by cotton roots. In the past, it was considered effective to use visual observations of leaves to diagnose nutrient element deficiencies. However, since nutrient deficiencies are not always observable, the term "hidden hunger" has entered the literature (Mengel and Kirkby, 1978). IPI (2014) explained the fact of "hidden hunger" very well with a graphic (Figure 3). Rehm et al. (1996) stated that 81-120 mg/kg of available K amount in soils was sufficient, while they evaluated above this amount as high. However, Demir and Dikici (2025) determined that K concentrations were insufficient in maize plant grown in a trial area with more K than these amounts. At the same time, when the researcher analyzed with the DRIS method, a yield-based mathematical modeling, he determined that the K index increased up to +30 on the scale in the low-yield population (<1200 kg/da) in the trial field, while it decreased to -18 in the high-yield population (>1200 kg/da). This situation proves that the amount of available K in the soil is insufficient with the increase in yield. Therefore, it should be known that the elemental values measured in lands are index values. With the agricultural developments, there has been a significant increase in yields. It is a more realistic approach to evaluate these measured values on a yield-based basis.

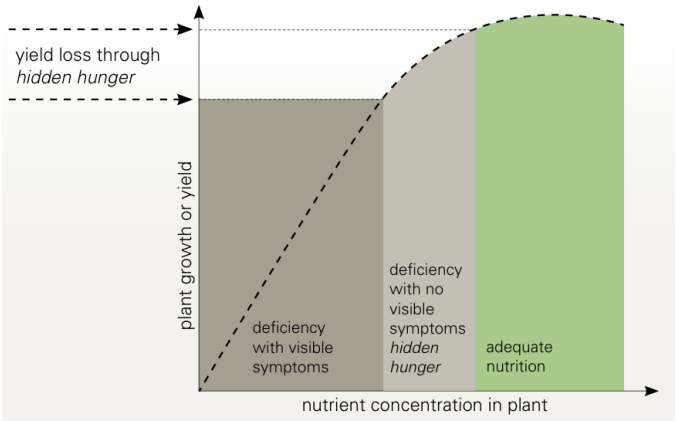



Figure 3. Illustration of the effect on yield or growth of a potassium deficiency (Retrieved from IPI, 2014)

## Geostatistical analysis and mapping

Nine different interpolation models were used to produce spatial distribution maps of the values obtained in the studied parameters, and the RMSE values of these models were determined (Table 3). From Table 3, it is understood that the Gaussian model of Simple Kriging for K and Ca, the spherical model of Simple Kriging for K/Mg and K/Ca, the exponential model of Simple Kriging for Mg, and the Gaussian model of Ordinary Kriging for K in the plant are the most suitable models. The lowest RMSE values were the exponential model of Simple Kriging in land and the Gaussian model of Ordinary Kriging in plants (Table 3).

Table 3. RMSE values according to different interpolation models

| | Kriging | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Ordinary | | | Simple | | | Universal | | |
| | *Gau. | *Exp. | *Sph. | *Gau. | *Exp. | *Sph. | *Gau. | *Exp. | *Sph. |
| K (mg/kg) | 1.0810 | 1.0918 | 1.0834 | 0.8677 | 0.8960 | 0.8773 | 1.0833 | 1.0918 | 1.0833 |
| Mg (mg/kg) | 0.9843 | 0.9421 | 0.9651 | 1.5180 | 0.7959 | 1.0230 | 0.9843 | 0.9422 | 0.9651 |
| Ca (mg/kg) | 0.9701 | 0.9989 | 0.9763 | 0.8884 | 1.0154 | 0.9073 | 0.9701 | 0.9989 | 0.9763 |
| K/Mg | 1.0976 | 1.0203 | 1.0636 | 0.9331 | 0.9525 | 0.8824 | 1.0976 | 1.0203 | 1.0636 |
| K/Ca | 1.0185 | 1.0204 | 1.0150 | 1.0095 | 1.0372 | 0.9968 | 1.1271 | 1.0443 | 1.0656 |
| K in plant, (%) | 0.4335 | 0.4363 | 0.4351 | 0.4337 | 0.4458 | 0.4337 | 0.4336 | 0.4364 | 0.4352 |

*Gau.: Gaussian, *Exp.: Exponential, *Sph.: Spherical

Figure 4 shows the distribution maps created according to the most appropriate interpolation models of the investigated parameters. Accordingly, it is understood that the distribution maps for K/Mg and K/Ca are relatively similar (Figures 4d,e), but the maps of other parameters are more different (Figures 4a,b,c,f). In Figure 4a, it is seen that the K in the land is sufficient from the north to the southwest of the Amik Plain and very high in other places. While there are very high concentrations of Mg in the north and middle of the study area, there are high contents of Mg in the remaining regions (Figure 4b). Ca is sufficient only in a small area in the north of the region, it is high in other places (Figure 4c). In Figures 4d and 4e, it is seen that the K/Mg and K/Ca ratios are sufficient in only two small areas in the southeast of the Amik Plain and insufficient in the remaining areas. Figure 4f shows that there is K deficiency in the plant in 51.27% (54,032.00 ha) of the study area. It is understood that these distribution maps supported our research hypothesis and the data obtained in the study.

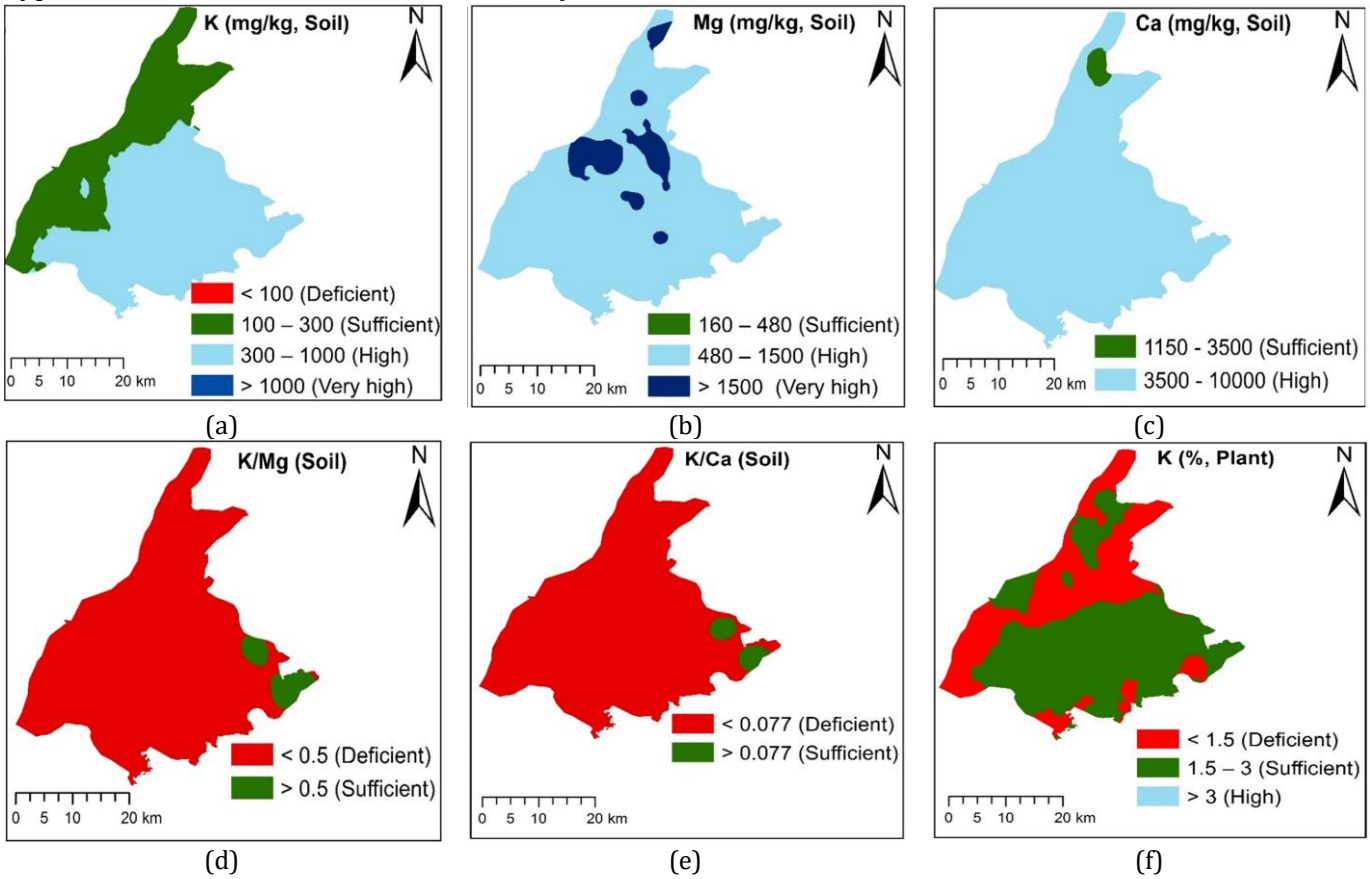



Figure 4. Kriging maps of the study area soils showing: a) extractable K, b) extractable Mg, c) extractable Ca, d) K/Mg ratio, e) K/Ca ratio, and f) K deficiency in plants

## Conclusion

First of all, this research will serve as a model for future studies in terms of its results. The research results showed that the rate at which lands are affected by extractable Mg and Ca-induced K deficiency is much higher than the existing K-induced K deficiency levels obtained from soil analysis. This proves that in lands where Mg and Ca concentrations are high enough to cause K deficiency, K values alone may not adequately indicate the presence of K. Therefore, the availability of an element is closely related to the amount of other cations in the solution. Consequently, when evaluating K status, the values of K obtained from plant analyses

should be considered along with the extractable K values in the land. K/Mg and K/Ca ratios should also be considered in determining the available K amount in the soil. Our research findings are in direct contradiction with the belief that agricultural soils contain sufficient K and that the use of K fertilizers is unnecessary. Accordingly, we strongly recommend that K fertilizers should be included in the fertilization program together with N and P fertilizers. In addition, whether the elemental concentrations obtained by soil analysis are valid for high yields should be investigated. In this respect, fertilizer recommendations need to be also updated according to studies targeting high efficiency.

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