

Chapter 8

Using Soil Tests to Evaluate Plant Availability of Potassium in Soils



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Abstract The purpose of this chapter is to describe how bioavailable soil K is assessed or predicted by soil tests. Soil testing commonly refers to the collection of a sample of soil representative of a field or agronomic management unit and, by way of extraction using chemical reagents, determination of the quantity of a nutrient that can be related to plant uptake or yield. Normally only a small fraction of the total quantity of the nutrient present in the soil is extracted during the procedure, but if that amount can be correlated with actual crop uptake or overall crop productivity, then the soil test is deemed to have useful predictive power.

Soil tests are routinely used to guide applications of fertilizer to soil so that crop demand for nutrients can be met effectively and economically. Here, we summarize the procedures involved in collecting a representative soil sample for K analysis, outline how that sample should be prepared for laboratory analysis, highlight the principles and mode of action of routine soil tests, and explore some common issues that may confound the correlation between a soil K test result and plant K acquisition or crop yield. Soil testing methods are discussed in the context of their relationship to the different forms of soil K and the in-soil chemical processes that may change these forms into K that can be taken up by roots.

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T. S. Murrell et al. (eds.), *Improving Potassium Recommendations for Agricultural Crops*, https://doi.org/10.1007/978-3-030-59197-7_8

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8.1 Sample Collection and Preparation

Regardless of the soil analytical method used, one of the greatest challenges in deriving a prediction of the fertilizer requirement for a field from a soil analysis is the accuracy with which the soil samples reflect the fertility status of the field, and specifically the parts of the soil profile that are exploited by crop roots. Therefore, a soil sample that purports to represent the K status of the crop root zone should be collected from the soil layers with most intense root activity during growth stages when K uptake is critical. The following aspects are of particular importance for K, given its relative immobility in all except coarse-textured soils, and given the relatively low proportion of plant K that is removed at harvest in many grain and horticultural crops.

8.1.1 Vertical Stratification

Most fertilizer K, as well as that from animal dung and urine, is typically applied to the soil surface, or only into shallow profile layers. In addition, a substantial proportion of the crop K content from all except forage and sugarcane (*Saccharum* spp.) crops is returned to the soil surface in crop residues. Tillage will redistribute residues and fertilizer K within the plow layer, but the increasing proportion of fields under minimum or zero tillage management, combined with less inversion tillage in conventional tillage systems, is increasing the importance of surface layer enrichment (e.g., Barré et al. 2009). Apparent stratification of surface soil K can be accentuated (typically) by plant K uptake from the subsoil that is not replaced in fertilizer programs (Kuhlmann 1990; Chap. 12), although this can be moderated in lighter textured soils by K leaching into the deeper profile layers (Williams et al. 2018). Collectively, these effects typically result in net K depletion from soil layers immediately below the cultivated zone in tilled systems or below the depth of fertilizer band application in no-till systems. The most substantial K depletion occurs in soil profile layers with high root densities and in drier environments (especially in clayey soils) where those soil layers retain sufficient moisture to support an extended period of root activity.

A soil sampling program should therefore ideally determine K status in multiple soil profile layers, with the temporal frequency of analysis of each layer determined by the predicted or assumed rate of net K depletion/enrichment. Few, if any, commercial testing programs currently implement such a structured approach, although the value of testing deeper soil profile layers has been demonstrated for both mobile and immobile nutrients (Bell et al. 2013a, b).

8.1.2 Spatial Heterogeneity in Response to Agronomic Management

Fertilizer K is often applied in bands, especially in row-crop systems, either as a single nutrient or as part of a fertilizer blend (Chap. 12). Without adequate soil mixing through tillage, the presence of residual K in old fertilizer bands will potentially distort soil sample K content. This spatial heterogeneity represents a particular challenge for soil sampling in minimum and no till systems, where soil mixing during seed bed preparation is limited.

Non-uniform distribution of crop residues across a field can also introduce spatial heterogeneity in soil nutrient status (Brennan et al. 2004), with effects on K more pronounced due to the relatively high proportion of crop K returned in residues—especially in grain and oilseed crops (Pluskie et al. 2018; Chap. 5). This heterogeneity is accentuated by consistent placement of crop residue windrows in precision-controlled traffic systems and where residues are deliberately concentrated to facilitate windrow burning as a means of reducing the seed bank of herbicide-resistant weeds. The increasing width of broadacre grain harvesters also makes uniform residue distribution more difficult to achieve. The result is increasing heterogeneity of soil K that needs to be recognized in devising an appropriate soil sampling strategy.

8.1.3 Sample Drying and Handling

Once collected, the soil sample should be prepared for analysis in a way that does not depart from the sample preparation method used in the soil test—crop yield (or crop K uptake) calibration studies on which the interpretation guidelines for the soil test are based. Soil samples are typically air- or oven-dried (generally at 40 °C) and then ground/crushed (typically <2 mm) to create a homogenous sample from which a portion is selected for analysis. However, the drying process can itself influence the results obtained from laboratory analyses, particularly estimates of bioavailable K (Martins et al. 2015). These effects are most pronounced in soils with mineralogy that supports K fixation and release (e.g., with significant amounts of illite, vermiculite, or smectite). In soils with known K fixation and release characteristics, soil drying can either increase, decrease, or have no appreciable impact on extractable K concentrations, depending on the soil's K status at sampling.

The likelihood of an increase in extractable K upon air-drying depends primarily on two factors: the amount of initially extractable and soluble K in the sample and the degree to which the sample is dried (Scott et al. 1957; Scott and Smith 1968; Haby et al. 1988). In general, when soil K concentrations are low, K is released upon drying of the sample, probably in response to multiple mechanisms, including exchange of cations like Ca^{2+} and H_3O^+ that increase in solution concentration as water evaporates, as well as “scrolling” of the weathered edges of clay sheets

(McLean and Watson 1985). However, when the initial concentrations of surface-adsorbed and soluble K are high, those concentrations will increase even further as water evaporates, and in response, K ions are more likely to move into wedge and interlayer positions of 2:1 minerals, leading to contraction of some interlayer spaces. Both release and fixation of K ions are therefore likely to occur simultaneously during drying of such samples, but the mechanisms that favor release will dominate in low-K samples and vice versa in high K samples. The “crossover point,” that is, the initial K status at which the ammonium-extractable K in moist samples is similar to that in dry samples, varies for each soil, most likely dependent on clay concentration, organic matter concentration, and soil pH.

Potassium fertilizer recommendations are most often developed using correlations between crop response and K extracted from air-dried samples with a uniform and low moisture content. However, some studies of soils with abundant 2:1 layer silicates have shown better correlations between soil K extractions from field-moist soil samples and crop responses to K fertilizer (Hanway et al. 1961, 1962; Barbagelata and Mallarino 2013). Adoption of an approach that uses field-moist samples may increase temporal variability in soil test results due to variation in moisture content, as well as requiring new approaches to homogenizing samples collected from soils with poor soil structure or high clay contents. However, if the improvement in prediction of bioavailable K status and crop fertilizer responsiveness is sufficient, such an approach will be warranted.

In soils where the mineralogy does not promote K fixation and release, effects of soil drying on extractable K are less important, and normal sample drying can be conducted without affecting the quantum of extractable K. While there are fewer studies of drying effects on extractable K in such soils, a recent investigation (Williams et al. 2017) found that soil drying method had no impact on the ability of Mehlich-3 soil extractions to predict responsiveness of soybeans to K in coarse-textured, sandy soils. Therefore, a knowledge of soil mineralogy and/or the presence of K fixation and release properties is necessary to develop soil drying protocols that do not interfere with the determination of bioavailable soil K status and that might confound the development of fertilizer recommendations.

8.2 What Are the Forms of Potassium in Soil?

Here we summarize the forms of K that are identified in the soil K cycle diagram (Fig. 1.1 in Chap. 1; Fig. 7.1 in Chap. 7). Potassium occurs in several pools, which are indicated by *boxes* in the diagram. The key constituents of each soil K pool, and the process by which K^+ ions move from one pool to another, are discussed in detail in Chaps. 1 and 7. Importantly, from the perspective of plant K uptake, it is the K ions in the soil solution that are most critical, since only that K can move to and into a root. While the application of fertilizer or contributions from plant residues can directly replenish soil solution K, several different solid-phase pools can also supply

the ion to the liquid phase by means of a variety of physical, chemical, or biological processes.

Overall, in considering the development of soil tests to determine the plant-available K status of a soil, K ions associated with minerals may be classified in four possible locations that are referenced in the K cycle diagram (Fig. 1.1 in Chap. 1). These are adsorbed on the exterior surfaces of negatively charged clay particles (*Pool 9*), in interlayer positions of clay-size illite, vermiculite, or smectite (*Pool 10*), deeply embedded in interlayer positions of mica particles (*Pool 11*), or embedded in the structure of feldspar crystals (*Pool 12*).

The main source of solution K replenishment from solid-phase pools is desorption of the ion from mineral surfaces and some clay interlayers. *Pools 9* and *10* can supply K to the soil solution and therefore to plants, although the mechanisms and rate of movement from solid phase to solution phase vary. The degree to which K ions enter the soil solution from these sources depends on several factors: the concentration of K^+ in the solution, competition from other cations in the solution, the amount and location of negative charge in the mineral crystals, the activity of hydronium ions at the crystal surfaces, the water content of the soil, the redox potential of the soil, the abundance of hydroxy-Al polymers in interlayer positions, and the activity of low-molecular-mass organic anions that can complex Al and therefore degrade mineral surfaces. Electrostatically adsorbed K ions on exterior surfaces (*Pool 9*) are readily susceptible to exchange with other cations in the soil solution or to displacement by high concentrations of other cations in soil tests.

Potassium ions that occur in the interior of silt- and sand-size particles as structural components of primary micas and feldspars (*Pools 11* and *12*), on the other hand, are not very accessible to the soil solution and therefore are assumed to contribute to plant-available K supplies very slowly. The rate of contribution may be increased when *Pools 9* and *10* are locally depleted by plant uptake or leaching or when hydrolysis and complexation reactions accelerate weathering of the primary minerals, but the rates of release generally remain insufficient to support crop production without fertilizer K amendments.

8.3 How Is Potassium Released from Different Solid-Phase Forms?

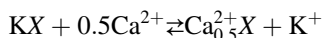
8.3.1 Potassium in Fertilizer and Crop Residues

Potassium ions must be in the soil solution before they can be taken up by plant roots in the transpiration stream. In an agricultural context, most inorganic K fertilizers are water soluble, so fertilizer K does not usually persist in solid granules in the soil for long after its application. As long as the soil is moist (i.e., soil moisture content is greater than that at permanent wilting point), there will be a rapid increase in soil solution K in response to fertilizer application.

In plant cells, K occurs in both the cytoplasm and in the liquid in the vacuole. As invertebrates and microbial enzymes attack the cells of crop residues, the cells' primary membranes and tonoplasts are broken, and cell fluids merge with the soil solution. Cell walls and membranes of crop residues are also disrupted by drying or burning, allowing K ions to rapidly enter the soil solution.

8.3.2 Surface-Adsorbed (Exchangeable) Potassium

Electrostatically adsorbed K ions may be released from mineral surfaces or organic components of a soil in response to low K concentrations in the soil solution. The degree to which this happens depends on the concentrations of K and other ions in the soil solution as well as the quantity of K that is adsorbed on mineral and organic matter surfaces. Ions that are electrostatically adsorbed on exchangers like minerals and organic matter are not bound tightly to specific sites, but they are in equilibrium with ions in the liquid phase. This can be illustrated in the symbolic exchange reaction below, where X = one mole of negative charge associated with the exchanger (mineral surface or organic matter). Ca^{2+} is chosen as a model divalent cation because it is usually more abundant in the soil than other cations, but here it stands in for other "exchangeable" cations like Mg^{2+} or Na^+ .



The equilibrium constant for this reaction is a selectivity coefficient, K_s , that expresses the preference for the exchanger to host Ca^{2+} over K^+ ions. The brackets indicate molar concentrations of ions in the solution, and the exchange-phase ion concentrations are moles of the ions per unit mass of the solid-phase.

$$K_s = \frac{\text{Ca}_{0.5}^{2+}\text{X}}{\text{KX}} \cdot \frac{[\text{K}^+]}{[\text{Ca}^{2+}]^{0.5}} \quad (8.1)$$

The first term on the right side of Eq. (8.1) is a ratio of charges associated with Ca^{2+} to the charges associated with K at the surface. The second term is a ratio of the concentration of K^+ in solution to the square root of the concentration of Ca^{2+} ions in the solution. In general, the larger the value of K_s is for a given soil or particular mineral, the greater is that material's preference for Ca over K. Selectivity is a function of the positive charge and the radius of each of the cations as well as the amount of negative charge and its location in the mineral.

When the exchange reaction is at equilibrium, there is still movement of ions between the exchanger and the solution, but the rate of the forward reaction is equal to the rate of the backward reaction. The value of K_s is relatively constant (at constant temperature and ionic strength), so the product of the ratios of charges in solution and charges near the solid surface, as shown in the equation, is also

constant. Therefore, if the concentration ratio of K^+ to other exchangeable ions (like Ca^{2+}) in the solution changes, the ratio of those charges on the exchanger's surface must also change.

This means that when the concentration of K^+ in the liquid phase drops below the concentration at equilibrium because of root uptake or leaching (i.e., the numerator of the solution term in Eq. (8.1) declines), release of surface-adsorbed K^+ to the solution (the left -to- right reaction) will begin and continue until equilibrium is re-established. Also, if the free Ca^{2+} concentration in the solution near a mineral surface increases, K^+ will be displaced as the reaction shifts to the right. Such displacement by Ca^{2+} is likely to occur, for example, as transpiration-induced mass flow of solution from the soil matrix moves into the rhizosphere and past the mineral edges and surfaces where K is adsorbed. Similarly, if the free Ca^{2+} concentration in the solution local to a mineral surface decreases—say, by complexation of Ca^{2+} with organic anions (e.g., oxalate or citrate), by leaching, by precipitation of insoluble apatites (calcium phosphates) as a result of ammonium-based phosphate fertilizer addition, or by preferential uptake of Ca^{2+} by a root—then the backward reaction will be favored, and K^+ will be more likely to move back from the solution phase to the exchange phase until equilibrium is again reached.

8.3.3 Chemical Weathering

Potassium-bearing minerals are transformed by both physical and chemical weathering. Here we focus on chemical weathering by describing some molecular-scale chemical reactions that are responsible for the release of K from structural positions in feldspar and mica crystals. Hydronium ions are released from roots into the rhizosphere to maintain electrochemical balance of charges when roots absorb cations (e.g., Ca^{2+} , Mg^{2+} , and NH_4^+) via the transpiration stream. Another source of hydronium ions is carbonic acid that forms when root-respired CO_2 enters the soil solution [$CO_2(g) + H_2O \rightarrow H_2CO_3 + H_2O \rightarrow H_3O^+ + HCO_3^-$]. Hydronium ions (H_3O^+) in the soil solution may play two kinds of roles in the weathering of mineral surfaces. First, they can be attracted to oxygen anions in $\equiv Al-O-Si \equiv$ bonds near crystal edges (where \equiv represents bonds to adjacent O^{2-} ions). When the bridging O accepts a proton from H_3O^+ , the Al-O bond at that location is weakened to the point of breaking, leaving $\equiv Si-OH$. The remaining H_2O molecule bonds with $\equiv Al$ to form $\equiv Al-OH_2^+$. As Al-O-Si bonds are broken in such hydrolysis reactions, gaps in the crystal open, and there is greater opportunity for structural K^+ ions near crystal edges to escape to the solution. Second, as crystal edges begin to break up and deteriorate, H_3O^+ may also exchange for K^+ ions in the structure, further accelerating the release of K^+ .

Dissolution of aluminosilicate minerals is also promoted by the complexation of Al^{3+} ions in solution by soluble organic anions such as oxalate and citrate. Low-molecular-mass organic anions are commonly exuded from roots or released during decomposition of crop residues and soil organic matter. At mildly acid to neutral soil

solution pH values (pH 5–7), each organic anion often has two or more negative charges, and the product of the reaction with Al may be a very stable, soluble complex (e.g., the complex of Al with oxalate: $[\text{C}_2\text{O}_4^{2-}(\text{Al}^{3+})^+]$). This reaction effectively limits re-precipitation of Al^{3+} ions at the mineral surface and thus prevents the degraded surface from being sealed with a poorly crystalline gel, thus allowing more opportunities for K^+ ions to escape to the solution phase.

A third potential mechanism of chemical weathering is the oxidation of Fe atoms in crystals of K-bearing minerals that contain Fe, such as biotite. Oxidation from Fe^{2+} to Fe^{3+} occurs when the redox potential of the solution around the crystal is high, such as in well-drained soils where O_2 from the atmosphere or H_2O_2 derived from rainfall are dissolved in the solution. Oxidation of Fe means that the positive charge on the Fe atom increases, so the *net* negative charge near that location in the crystal decreases, making nearby K^+ ions more susceptible to exchange reactions with other cations. Eventually, the charge imbalance caused by oxidation can result in expulsion of Fe ions from the crystal, further weakening the structure and allowing even more K to move to the solution phase.

8.4 How Do Soil Tests Assess Plant-Available Potassium?

8.4.1 Soil-Test Development

The goal of any soil fertility test is to provide crop producers with a rapid, inexpensive, reproducible value that can be used to predict the need for, or outcome of, soil amendments or other management actions. Soil K test values are intended to provide guidance for whether application of K fertilizer would be beneficial in a typical growing season and, if so, by how much. For example, most soil tests for K assume that readily plant-available K ions in a soil sample are adsorbed to minerals and organic matter by electrostatic forces, and they can therefore be readily displaced by a high solution concentration of another cation, such as ammonium. Therefore, several soil-test procedures involve mixing or leaching a soil sample with a solution with a high concentration of an ammonium salt and measuring the amount of K that is moved to the liquid phase as a result. The displacement process is fast, the salt is inexpensive, and when all experimental parameters are standardized, the procedure itself is reproducible. Such displacement reactions are extreme examples of chemical exchange reactions. Several decades of international research efforts have focused on methods to relate concentrations of this “exchangeable” soil K to crop demand, crop uptake, and crop yield. Sometimes this form of K is called “plant-available,” although the correlation between, say, ammonium-displaceable K and K taken up by plants is an indirect inference.

However, exchangeable soil K tests are not always highly correlated with plant response. In some soils, soil-test K values may suggest the need for fertilizer K, but when it is not applied, the crop is still able to remove enough K from the soil to produce a respectable (but possibly sub-optimal) yield. The sources of K in such

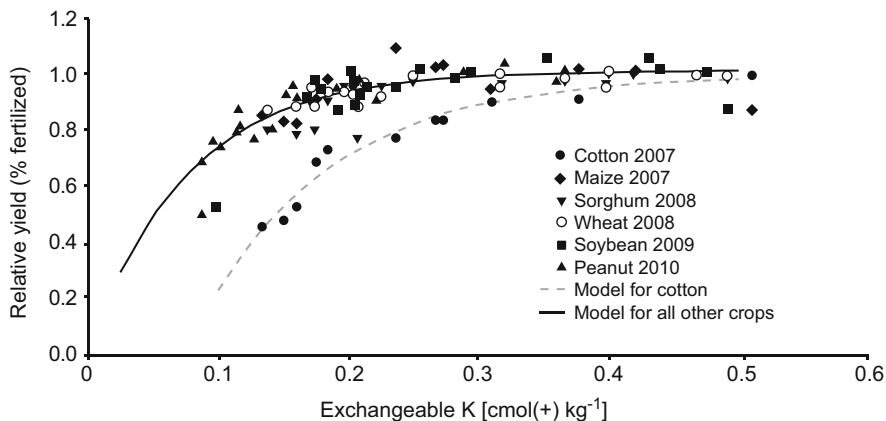


Fig. 8.1 Relationship between exchangeable K (by ammonium displacement) [$\text{cmol}(+) \text{kg}^{-1}$] in the top 10 cm of the soil profile and relative grain or fiber yield for different crops grown over a sequence of crop seasons on an Oxisol soil in northeastern Australia

soils may include hydroxy-interlayered vermiculite, biotite, or feldspars. Furthermore, most soil K test extractions do not provide information about the *rate* of K release from the soil during the growing season, and it is often the rate of release that determines whether a crop response to fertilizer will occur.

Over the time frame of a single season, correlations between exchangeable K and crop K uptake or grain yield can be used to identify a “critical” soil-test K value (or range) that indicates K sufficiency for different crops; for example, cotton has a higher critical value for exchangeable K (by ammonium displacement) than other species (Fig. 8.1).

However, when adequate K needs to be supplied over longer time periods (such as occurs with repeated biomass removal in forage cropping, or perennials, or high biomass-high K demand crops such as sugarcane), there are many soils from which plants are able to extract more than the initially exchangeable K pool. For example, Fig. 8.2 illustrates that K removal by crops may average almost 160% of the measured change in exchangeable K (by ammonium displacement). In this situation, *pools 9, 10, and/or 11* (depending on soil mineralogy) are buffering soil solution K (and thereby, exchangeable K). The change in K extracted by tetraphenyl borate (TPB) (TB-K1h—described later) was a better indicator of the cumulative K removal in biomass than the change in exchangeable K (by ammonium displacement) (Fig. 8.2).

Plant K uptake over an even longer period can be derived from multiple K pools in the soil. For example, a study of empirically defined K pools of an Oxisol in northeastern Australia shows that change in the soil profile exchangeable K (by ammonium displacement) to a depth of 90 cm only accounted for 41% of the K removed from the total K pool over four decades (Fig. 8.3). It is apparent that over this extended uptake period, soil solution K was buffered not only by exchangeable K but also by K pools that are reflected by the TB-K 1 h. extraction, the boiling 1 M

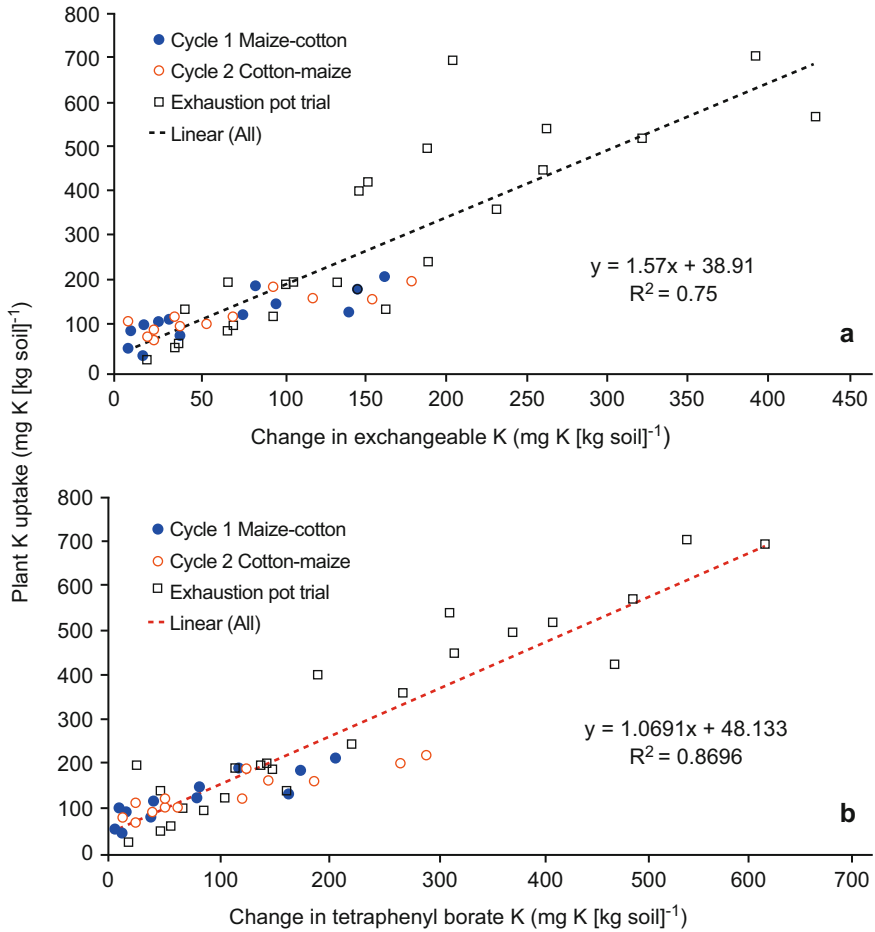
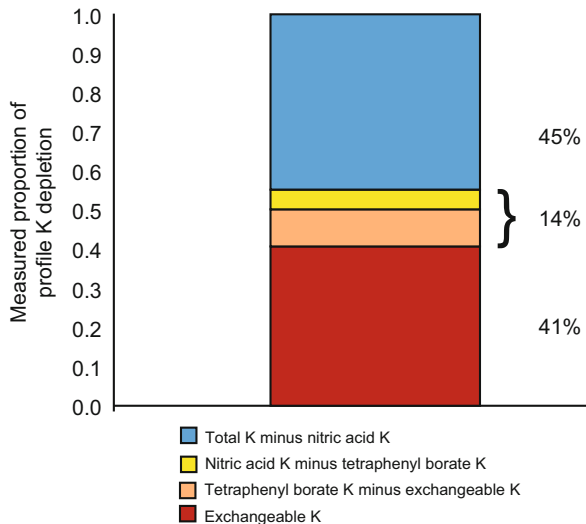


Fig. 8.2 The change in (a) exchangeable K (by ammonium displacement) and (b) tetraphenyl borate-extractable K (1 h) in response to plant K removal resulting from growing sequential maize (*Zea mays*) and cotton (*Gossypium* spp.) (or vice versa) crops, or a sequence of forage harvests (exhaustion pot trial) on neutral to alkaline medium-heavy clay soils in Australia

nitric acid extraction (described later), and the residual K fraction not extracted by any of the other extractants (Fig. 8.3).

The availability of K to plants is therefore determined by: (1) the quantities of K present in the different soil pools depicted in Fig. 1.1 (Chap. 1); (2) the rate of replenishment of soil solution K from those pools as K is removed by plant uptake or other processes; and (3) the period over which crop K uptake is measured. It is apparent that soil K tests reflecting one or more of these K supply factors will be required to predict the bioavailable K status in different cropping systems. The most

Fig. 8.3 The proportional change in soil K content to a depth of 90 cm resulting from 40 years of annual grain or forage cropping that can be accounted for by different soil tests. Data are from paired cropped and uncropped sites on an Oxisol in northeastern Australia



useful predictive test(s) will be the one(s) best correlated with the factor(s) governing K availability in any particular soil and growing season.

Accordingly, commonly used soil K tests have been grouped together in Table 8.1 on the basis of the processes that occur during the extraction: (1) equilibrated solution; (2) cation exchange; (3) acid dissolution; (4) multiple mechanisms, including complexation; and (5) rate of solution K replenishment. In addition, for a chemical extractant to be attractive for routine commercial application, it is advantageous if other nutrients (e.g., Ca, Mg, or P) can also be extracted by the same test and similarly correlated with plant uptake. Depending on the processes occurring during the extraction, the soil-extractant ratio, the extraction time and the extraction pH, inferences can be drawn about which K pools are likely to be contributing to the quantum of extracted K.

To organize the following discussion of soil tests to assess plant-available K, we have listed the extractions by numbers in Table 8.1, and we refer to those numbers in the narrative.

8.4.2 Soil Tests for Assessing Soil Solution Potassium

One soil K test intended to reflect K concentrations similar to those that roots might encounter in the soil solution is an extraction with 0.01 M CaCl₂ (Houba et al. 2000; extraction [1] in Table 8.1). The concentration of the salt simulates a typical ionic strength of soil solution, although the ionic strength of 0.06 M is higher than that often observed in highly weathered soils (≈0.005 M, Gillman and Bell 1978). The Ca²⁺ ions in the extractant are expected to partially displace electrostatically bound K⁺, NH₄⁺, Mg²⁺, and Na⁺ ions, and the Cl⁻ ions are expected to partially displace

Table 8.1 Soil tests to assess bioavailable K

Extraction process	Method and reagents	Concentration of reagents	Initial pH	Solid-solution ratio and other parameters	References and comments
Equilibrated solution	1. CaCl ₂	CaCl ₂ 0.01 M	Buffered by soil	1 g:10 mL, 2 h or 7 day	Houba et al. (2000) (2 h) and Cassman et al. (1990) (7 day)
	2. H3A multi-nutrient extractant	Li citrate, 0.010 M; citric acid, 0.003 M; malic acid, 0.003 M; oxalic acid, 0.004 M	4.4	1 g:10 mL, 5 min	H3A extract of Haney et al. (2010); extracts about one-third of the K extracted by NH ₄ acetate
	3. Ammonium acetate at pH 7.0	NH ₄ acetate, ~1 M	7.0	1 g:10 mL 2.5 g:25 mL 2.5 g:50 mL	Helmke and Sparks (1996) (shake 5 min), Gavlak et al. (2005) (shake 30 min), and Burt and Soil Survey Staff (2014) (leach 12 h on vacuum extractor)
	4. Ammonium acetate at pH 4.8 (Modified Morgan)	NH ₄ acetate, 1.25 M; NH ₄ OH, 0.62 M	4.8	4 cm ³ :20 mL; 5 min	Mchintosh (1969) and Wolf and Beegle (2011)
	5. Ammonium chloride	NH ₄ Cl, 1 M	Buffered by soil	2.5 g:50 mL; 12 h on mechanical vacuum extractor	Burt and Soil Survey Staff (2014)
	6. Ammonium bicarbonate (AB-DTPA) at pH 8	NH ₄ HCO ₃ , 1 M; diethylene triamine pentaacetic acid (DTPA), 0.005 M	7.6	3 g:20 mL; 15 min	Soltanpour and Schwab (1977); designed for alkaline soils; NH ₄ ⁺ used to displace base cations; bicarbonate used to displace phosphate; DTPA added to complex trace metals
	7. Ammonium lactate	NH ₄ lactate, 0.1 M; CH ₃ COOH, 0.4 M	3.75	5 g:100 mL; 90 min	Egnér et al. (1960) and Salomon (1998); used in Sweden for P and K; NH ₄ ⁺ exchange with K and other base cations; pH buffered by acetic acid

Exchange by other cations	8. Colwell	Na bicarbonate, 0.5 M	8.5	1 g:100 mL, 16 h	Colwell (1963)
	9. Na exchange—Morgan	Na acetate, 0.73 M; acetic acid, 0.52 M	4.8	10 cm ³ :50 mL, 5 min	Morgan (1941) and Wolf and Beegle (2011)
	10. CALS (Ca acetate and lactate)	Ca acetate, 0.05 M; Ca lactate, 0.05 M;	4.1	1 g:20 mL, 90 min	Schüller (1969) and Zbrtal and Némec (2005); developed primarily as an extractant for P; used in Germany for P and K
Acid dissolution	11. BaCl ₂ (with NH ₄ ⁺) exchange	BaCl ₂ , 0.1 M; NH ₄ Cl, 0.1 M	Buffered by soil	2 g:20 mL, 2 h shake in water 1 h before adding the BaCl ₂ and NH ₄ Cl	Gillman (1979) and Gillman and Sumpter (1986); developed for variable charge soils, but suitable for all soils
	12. Mehlich 1—Double acid	HCl, 0.05 M; H ₂ SO ₄ , 0.025 M	1.2	4 cm ³ :20 mL, 5 min	Mylavarapu and Miller (2014); developed for acid, sandy soils
	13. Nonexchangeable K: Strong acid dissolution	HNO ₃ , 1 M	0.1	2.5 g:25 mL, 386 K, 25 min	McLean and Watson (1985); nonexchangeable K computed by difference between the total K removed and that exchangeable with 1 M NH ₄ ⁺ acetate, pH 7
Multiple mechanisms	14. Mehlich 3	CH ₃ COOH, 0.2 M; NH ₄ NO ₃ , 0.25 M; NH ₄ F, 0.015 M; HNO ₃ , 0.013 M; EDTA, 0.001 M	2.5 ± 0.1	1 g:10 mL, 5 min	Mehlich (1984); not recommended for K in calcareous soils; pH buffer; NH ₄ ⁺ exchange with K and other base cations; F ⁻ complexes Al and Si; hydrolytic attack at mineral surfaces; complexes trace metal nutrients
	15. Kelowna with EDTA or DTPA	CH ₃ COOH, 0.25 M; NH ₄ F, 0.015 M; EDTA or DTPA, (0.001 or 0.005 M)	2.7–3.0	1:10 by volume, 5 min	Van Lierop and Gough (1989); pH buffer; F complexes Al, Si; NH ₄ ⁺ exchange with base cations

(continued)

Table 8.1 (continued)

Extraction process	Method and reagents	Concentration of reagents	Initial pH	Solid-solution ratio and other parameters	References and comments
Sinks	16. Modified Kelowna	CH ₃ COOH, 0.025 M; NH ₄ acetate, 0.25 M; NH ₄ F, 0.015 M	4.9	1:10 by volume, 5 min	Qian et al. (1994); designed to extract more K than the original Kelowna extraction; pH buffer; NH ₄ ⁺ exchange with K and other base cations; F ⁻ complexes Al, Si; NH ₄ ⁺ exchanges with base cations
	17. Lancaster	Solution A: HCl, 0.05 M; Solution B: glacial acetic acid, 1.57 N, plus compounds listed below: malonic acid, 0.063 M; malic acid, 0.089 M; NH ₄ F, 0.032 M; aluminum chloride hexahydrate 0.12 M	1.4 4.0	1st step—5 g:5 mL HCl for 5 min, no shaking Second step—add 20 mL of solution B to first step, 10 min shaking	Cox (2001) and Oldham (2014); pH buffer; Intended to complex Al; F ⁻ sufficient to complex Al, but concentration is thought to be low enough to prevent precipitation with Ca and Mg; Al is also added to prevent F ⁻ precipitation with Ca and Mg
	18. Cation exchange resin: Na exchange for K	Na-saturated cation exchange resin (sulfonated polystyrene)	6.8	1:1 volume ratio; 16 h shaking with a previously disaggregated sample	van Rajj et al. (1986). Na-saturated cation exchange resin (sulfonated polystyrene) coupled with bicarbonate-saturated anion exchange resin (quaternary ammonium functionality) for anions. 1 M NaHCO ₃ is used to saturate the resins
	19. Nonexchangeable K: Na tetraphenylboron	Na tetraphenylboron, 0.2 M; NaCl, 1.7 M; EDTA, 0.01 M		0.5 g:3 mL; 1, 5, 15, or 60 min incubations	Cox et al. (1996, 1999)

Water-soluble K is extracted with all of these extractants, but its concentration is assumed to be negligible in non-saline soils and is ignored

weakly held phosphate species, SO_4^{2-} , and NO_3^- ions. Other nutrients and contaminants may also be determined in the extract. Because the soil-solution ratio and the physical disruption caused by shaking the soil sample with the extractant do not simulate normal soil conditions, the extracted nutrient concentrations must be understood as indices of nutrient concentrations one might expect in a soil solution, not absolute values.

A number of studies have shown that the CaCl_2 extraction solubilizes less K than the ammonium acetate, Mehlich 3, or ammonium lactate extractions (e.g., Simonis and Setatou 1996; Baier and Baierova 1998; Zbírál and Němec 2005; Woods et al. 2005; Salomon 1998). The differences in the extraction results are probably due to the relatively low concentration of Ca in the CaCl_2 extractant as well as to the lower hydration energy of ammonium, which allows it to penetrate clay interlayer spaces more effectively than Ca. While there is typically a strong correlation between CaCl_2 -extracted and ammonium-extracted K, generally, 0.01 M CaCl_2 extracts only 30–80% of the K removed by the more aggressive extractions. The amount of K solubilized increases at lower clay concentrations, suggesting that the efficiency of Ca^{2+} to exchange with K^+ declines when more clay is present (i.e., when the cation exchange capacity is higher or when clay microaggregates are less likely to be rapidly dispersed).

Haney et al. (2010) proposed a multi-element extraction, called H3A ([2] in Table 8.1), intended to simulate the solution in the rhizosphere by a suite of dilute organic bases like those that might be exuded by roots, including citrate, oxalate, and malate. The only cation present in this extractant is Li^+ , and it is present at a low concentration. Comparisons of nutrient concentrations released by the H3A extractant with those of other, more aggressive extractions have been few, and we are not aware of calibration studies relating solubilized nutrient concentrations with crop growth or yield. In a comparison of K extracted by the H3A extractant with K extracted by ammonium acetate, H3A solubilized only about one-third of the ammonium-extractable K in 60 soil samples from the continental United States (Haney et al. 2010). The H3A extraction has recently been modified by removing Li citrate from the reagents in the extraction solution (Haney et al. 2017).

The assumption behind both the CaCl_2 and H3A extractions is that extractants similar to the soil solution will provide more accurate knowledge of the instantaneous bioavailability of soil nutrients. While the extracted concentrations of K may be correlated with those of other extractants, significant advantages of the CaCl_2 and H3A extractants over ammonium-based procedures for predicting seasonal K needs for a crop have yet to be demonstrated.

8.4.3 Soil Tests for Assessing Surface-Adsorbed Potassium

The ammonium ion, NH_4^+ , has similar size, charge, and hydration energy to the K^+ ion. For this reason, ammonium has been preferred as the cation most likely to replace K that is surface-adsorbed or located in readily accessible interlayer positions

of soil minerals. Several soil-test extractions have been developed for this purpose. These include extractants with high concentrations (≥ 1 M) of ammonium acetate (e.g., [3], [4] in Table 8.1), ammonium chloride ([5] in Table 8.1), and ammonium bicarbonate ([6] in Table 8.1) (Burt and Soil Survey Staff 2014; Wolf and Beegle 2011; Soltanpour and Schwab 1977). The 1 M ammonium acetate and ammonium chloride extractions also promote displacement of other exchangeable cations such as Ca^{2+} , Mg^{2+} , and Na^+ . The ammonium lactate extraction [7] employs ammonium at a lower concentration (0.1 M) than the previously mentioned extractions.

In high pH, calcareous soils, exchangeable Ca and Mg do not limit crop nutrition, and the ammonium bicarbonate extraction (AB-DTPA) focuses not only on extraction of bioavailable K^+ , but also on phosphate ions (presumably by exchange of HCO_3^- with HPO_4^{2-}). DTPA is added to the AB-DTPA extractant to complex micronutrient trace metals (Zn, Fe, Mn, and Cu). The modified Morgan extraction ([4] in Table 8.1) has an even higher concentration of ammonium (1.87 M) and is used to extract K, Ca, Mg, P, Cu, Mn, and Zn.

Cations other than ammonium may be used to displace K^+ from exchange sites; these include Na^+ (e.g., Colwell extraction, [8], in Table 8.1 and the original Morgan extraction, [9], in Table 8.1), Ca^{2+} (CALs extraction: [10] in Table 8.1), and Ba^{2+} (the BaCl_2 extraction, [11], in Table 8.1). In soils where all exchange sites are equally accessible, these ions are expected to displace surface-adsorbed K^+ effectively, especially when employed at high concentrations compared to the concentration of extractable K in the soil sample. However, the larger hydrated radius and hydration energy of Na make its entry into interlayer spaces difficult, so it is much less likely to displace K^+ ions in those locations. Similarly, the much higher energies of hydration of Ca^{2+} and Ba^{2+} ions mean that the hydration spheres of these divalent cations are also stable enough to prevent entry into interlayer spaces, even though the ions are competitive with K at external mineral surfaces. Primarily for this reason, ammonium-based extractants are preferred to assess bioavailable K in soils where 2:1 layer silicates are present and interlayer K is likely to occur.

Extractants that exchange ammonium or other cations for K are also distinguished from one another by the pH of the extraction. Maintaining a constant, buffered pH during the extraction period (7.0 for 1 M ammonium acetate, 7.6 for AB-DTPA, 4.8 for the modified Morgan extractant, 8.5 for the Colwell extractant), while not expected to affect significantly the amount of K extracted, may affect the extractability of other nutrients. The pH of the modified Morgan extraction (pH 4.8) was chosen to simulate the pH of the soil solution in equilibrium with high concentrations of CO_2 (g) and organic base anions, as the solution adjacent to a root hair may be during active root respiration. For acidic soils that are not highly weathered, pH ~ 7 is a common target for optimizing plant growth; thus 1 M ammonium acetate at pH 7 may better represent K ions that would be bioavailable if the field soil pH were adjusted by adding lime. In the AB-DTPA extraction, pH is maintained high enough that calcite (calcium carbonate) will not be dissolved during the extraction. The pH of the ammonium acetate extraction may also be adjusted (e.g., to 8.5) to minimize dissolution of calcite in calcareous soils.

8.4.4 Soil Tests for Dissolving Interlayer/Structural Potassium

Some soil K tests have been developed to simulate the chemical processes that lead to K release from pools other than exchange sites. For example, the Mehlich-1 extraction ([12] in Table 8.1) creates a low-pH environment so that nutrients (base cations, P, and micronutrients) will be solubilized by hydronium exchange or by hydrolysis reactions. The Mehlich-1 extract relies on 0.05 M HCl and 0.025 M H₂SO₄ to provide an excess of hydronium ions to partially dissolve nutrient-bearing minerals as well as to displace electrostatically adsorbed base cations and to compete with complexed micronutrient metals at variable-charge sites.

The strong acid extraction described by McLean and Watson (1985) [13] comprises boiling a soil sample in 1 M nitric acid for 25 min, amplifying the intensity of the hydrolysis reaction to dissolve K-bearing silicates. “Non-exchangeable” K is estimated by the difference between the acid-soluble K and ammonium-displaceable K (1 M NH₄⁺ acetate, pH 7). While the results of this extraction have been correlated with plant uptake of K in some studies, at least a portion of the K released is likely to derive from interlayers of primary micas and the interiors of feldspar crystals—i.e., K that would not be very available to plants in a single growing season.

8.4.5 Soil Tests that Combine Multiple Mechanisms of Potassium Dissolution

Several multi-element soil extractants have been developed that employ ammonium salts in concentrations lower than those of the preceding extractions, but they also include reagents that promote mechanisms other than cation exchange for solubilizing K. For example, the concentration of NH₄⁺ ions in the Mehlich-3 extractant ([14] in Table 8.1) is 0.265 M. In the Kelowna extractant with EDTA ([15] in Table 8.1) and the modified Kelowna extractant at pH 4.9 ([16] in Table 8.1), it is 0.015 M and 0.265 M, respectively. In the Lancaster extractant ([17] in Table 8.1), the concentration of NH₄⁺ ions is 0.032 M. Typically, K extracted by these methods is compared with the 1 M ammonium acetate extraction for effectiveness. By using the Kelowna extraction (with EDTA or DTPA), van Lierop and Gough (1989) reported that ~20% less K was solubilized, on average, in 100 Canadian soils than by using the 1 M ammonium acetate extraction. However, in a subsequent modification of the Kelowna extractant, increasing the ammonium ion concentration to 0.265 M increased extractable K by ~30% (i.e., similar to the ammonium acetate extraction for soils with extractable K < 450 mg kg⁻¹) and significantly improved the relationship between extractable K and K uptake by canola (Qian et al. 1994).

In the Mehlich 3, Kelowna (both versions), and Lancaster extractions, all or a portion of the ammonium added to the extractant is in the form of NH₄F. The fluoride ion is added primarily because it forms strong complexes with Al³⁺, helping

to dissolve Al oxyhydroxides and release adsorbed orthophosphate ions. Mehlich (1984) reported that 6–8% more K was extracted by Mehlich 3 than by 1 M ammonium acetate in a suite of 105 soils from the southern and eastern United States. It may be speculated that the added F^- can also contribute to dissolution of Al from hydroxy-interlayered vermiculite, thereby facilitating $NH_4^+ - K^+$ exchange. This complexation reaction may be compared with weathering of micas in the presence of organic compounds. Low-molecular-mass organic anions (e.g., oxalate, malate, and citrate) may complex Al^{3+} , limit re-precipitation of Al^{3+} ions at mineral surfaces, and therefore promote K exchangeability.

8.4.6 Soil Tests for Assessing the Rate of Solution Potassium Replenishment

By varying the extraction time, soil K tests that provide a sink for K released into the soil solution can be used to assess the rate of solution K replenishment in response to depletion by plant uptake or other processes. The mixed bed cation-anion exchange resin method ([18] in Table 8.1) was designed to simulate plant uptake of nutrients by providing a strong sink for both cations and anions. The sink creates a strong disequilibrium that favors nutrient release from the soil sample. In the case of K, one cation exchange resin that has been used is a Na-saturated sulfonated polystyrene that strongly adsorbs cations. The K extracted by this method from Oxisols, Ultisols, and Alfisols with low cation exchange capacity (CEC) in Brazil was very similar to K extracted by 1 M ammonium acetate and 0.025 M H_2SO_4 (van Raij et al. 1986). The method has been successfully adapted for routine processing of large numbers of soil samples in a single, overnight extraction period.

The tetraphenyl borate extraction method ([19] in Table 8.1) was developed by Cox et al. (1996, 1999) on the basis of work by Scott and colleagues (e.g., Scott and Reed 1962) and exploits the strong complexing power of tetraphenyl borate for alkali metals. Short reaction times have been correlated with release of K from vermiculite interlayers, but the longer the reaction is allowed to proceed, the more K can be pulled from primary minerals, too.

Variations of both the resin method and the tetraphenyl borate method could be used to characterize the rate of release of K into solution from the various soil pools. In a glasshouse experiment, Moody and Bell (2006) found that the absolute changes in TB-K (1 h) in 37 soils of diverse chemistry were more highly correlated with exhaustive cumulative crop K uptake than changes in TB-K (15 min), with regression slopes of 0.99 (± 0.04) and 1.12 (± 0.07), respectively. These results demonstrate that the rate of replenishment of solution K is important to K bioavailability, but this effect is unlikely to be captured by a single extraction. Multiple temporal assays to measure the rate of K release are probably not feasible in a commercial

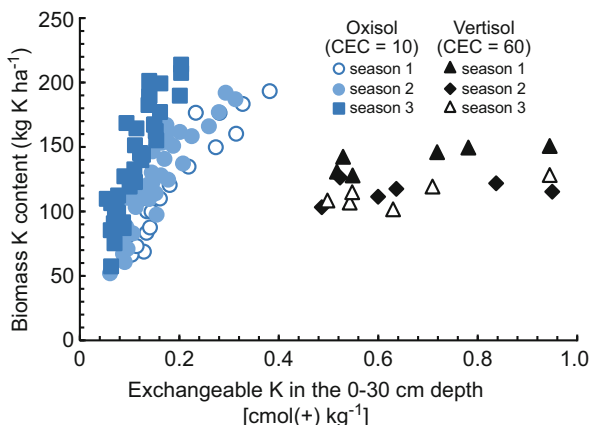
laboratory setting, and the resin or TPB approaches will likely remain as research tools to better understand the interactions among the various K pools.

8.5 Difficulties Relating Soil Test Potassium to Crop Acquisition

A number of the processes already discussed in this chapter will clearly affect the usefulness with which a soil test can predict crop K acquisition. These include the applicability of the soil K test extraction method to estimate the K pools that contribute to plant uptake, the period for which K availability is being predicted (single crop, multiple harvests, multiple growing seasons), and the intensity of K demand during the growth period.

However, as illustrated in Fig. 8.4, even the same crop species and cultivar growing on two contrasting soil types within the same crop region in northeast Australia exhibited very different responses to increasing soil test K, despite similar maximum yields and crop K demand. The soils in Fig. 8.4 (an Oxisol with a CEC of 10 cmol(+)/kg and a Vertisol with a CEC of 60 cmol(+)/kg) both supplied K from the exchangeable K pool. However, as exchangeable K increased in response to K fertilizer addition, grain sorghum growing in the Oxisol was able to accumulate K much more efficiently, and to a greater extent, than grain sorghum growing in the Vertisol. Despite the choice of soil test methods appropriate for assessing soil K pools that can meet crop K demand and sampling depths that reflect crop root activity under those environmental conditions, these different patterns of crop K acquisition demonstrate the impact of other factors that should be considered when interpreting a soil test K result. These are discussed briefly below.

Fig. 8.4 The relationship between exchangeable K (by ammonium displacement) and accumulation of K in aboveground biomass of grain sorghum grown in each of three different growing seasons on an acidic Oxisol (CEC 10 cmol(+)/kg) and an alkaline Vertisol (CEC 60 cmol(+)/kg)



8.5.1 Rates of Resupply to Potassium-Depleted Zones Around Active Roots

The replenishment of soil solution K in response to depletion by plant root uptake is dependent on: (1) the solution K concentration in undepleted soil; (2) mass flow of that soil solution to the root in response to crop water extraction; and (3) diffusion of K along a concentration gradient between the depleted rhizosphere soil solution and that of the surrounding undepleted soil (see Chap. 7). The contrasting relationships between exchangeable K and K acquisition by sorghum (Fig. 8.4) illustrate the effect of soil properties on aspects relating to both (1) and (3). The much higher CEC in the Vertisol results in lower soil solution K concentrations in undepleted soil (e.g., Bell et al. 2009), which by itself can limit K supply to the root (Barber 1995). However, this soil characteristic will also limit the K concentration gradient that can develop between the depleted rhizosphere and the undepleted soil solution. In addition, physical impediments related to poor soil structure and porosity affect the tortuosity of the diffusion path that K ions must traverse to reach the depleted rhizosphere, and they can therefore influence the rate of rhizosphere replenishment (e.g. Barber 1995; Dodd et al. 2013). Solution K in the Oxisol, which is porous and strongly structured, has a much less tortuous diffusion path than in the Vertisol and therefore allows more rapid rates of K diffusion into the rhizosphere. Collectively, these soil characteristics contribute to the more rapid plant uptake of K in the Oxisol in response to incremental increases in exchangeable K that are presented in Fig. 8.4. From the perspective of soil test interpretation and K fertilizer recommendations, lighter textured soils that have low K buffer capacities (i.e., limited ability to hold K in pools other than the soil solution) and can support high K diffusion rates are likely to have lower critical soil test K concentrations (e.g., Brennan and Bell 2013) and will respond to lower rates of applied K (e.g., Bell et al. 2009).

8.5.2 Root System Architectures and Their Interaction with Soil Moisture

This topic is covered in depth in Chaps. 4 and 12, respectively, from the perspective of the relative advantage of different root morphologies in systems with contrasting seasonal moisture availability and profile K distributions. These characteristics interact with the efficacy of different K fertilizer application strategies. They are especially relevant in the consideration of the depths from which soil samples are to be collected, as these need to reflect the root characteristics of the target species for which K availability or fertilizer requirement is being predicted. The data presented in Fig. 8.1 provide a good example of the relative disadvantage of the coarse root system of cotton in being able to efficiently acquire K from a soil profile in which K is strongly stratified, in comparison to root systems of other crop species grown in the same soil and seasonal conditions. Other examples of the impact of root

morphology on K acquisition include the report by Witter and Johansson (2001) that illustrated the advantage of deeply rooted forage species such as lucerne/alfalfa (*Medicago sativa*) and chicory (*Cichorium intybus*) in acquiring K from subsoil layers.

The interaction of root morphological characteristics with seasonal moisture availability is a further complication in choosing the depth of soil sampling, the critical soil test concentration used to determine adequacy of soil K status, and any subsequent fertilizer placement strategy. Soil layers that are periodically dry during the growing season are less likely to contribute a substantial proportion of plant K uptake. Therefore, cropping systems where seasonal variation in rainfall amount and distribution alter the reliance on topsoil and subsoil K reserves provide additional challenges to predicting K availability from soil test results.

8.5.3 Variation in Root System Attributes that Allow Plants to Exploit Different Potassium Pools

Chapter 4 focuses on the foraging strategies that plants use to increase the volume of the rhizosphere from which they acquire K, and provides a more detailed coverage of this topic. Briefly, there are many examples where more aggressive depletion of the rhizosphere K by plant root systems [e.g., by ryegrass (*Lolium*) (Barré et al. 2007, 2008)], an ability to more extensively lower rhizosphere pH (Hinsinger et al. 1993), or an ability to release exudates that promote the dissolution of K-bearing silicates (Song and Huang 1988) can provide plant species or genotypes with greater access to less readily available K pools. These characteristics could potentially affect the choice of diagnostic soil test if the differences are large enough. However, it is more likely that they would simply reduce the precision with which a particular soil test could identify a critical soil concentration above which fertilizer responses would be less probable. Given the move toward diversity in crop rotations and the speed with which new cultivars are introduced into agricultural systems, the ability to precisely define soil test-crop response relationships for a single crop species is likely to remain challenging.

8.5.4 Specificity of Soil Test Potassium-Crop Response Relationships and the Role of Trial Databases

There are clearly many challenges that will constrain our ability to develop robust soil test-crop response relationships that can cope with spatial variability in soil types, seasonal variability in access to different soil profile layers, and different genotypes and species in a crop rotation. These challenges have contributed to the commonly reported site-specific nature of soil test-crop response relationships for K

(e.g., Brouder et al. 2015). While greater process-level understanding may help explain the reasons for variation in soil test-crop response relationships, the rate of knowledge gain is unlikely to be able to keep up with the rate of management-induced changes in profile K status and distribution, or the changes in cultivars being delivered from breeding programs.

One approach to increasing the rate of accumulation of soil test-crop response data is the development of searchable databases that allow aggregation of available data at an appropriate scale (e.g., regionally or on the basis of soil type). An example of this has been the Better Fertilizer Decisions for Cropping database and database interrogator developed in Australia (Whatmuff et al. 2013), which currently houses in excess of 5500 historic data sets from trials that have been used to develop soil test-crop response relationships for N, P, K, and S. New experimental data are also being added to this database, allowing not only the greatest density of trials to build soil test calibrations but also an opportunity to explore the impact of time and management changes on critical soil test values (e.g., the change from conventional to zero tillage for less mobile nutrients like P and K). A relevant example of the use of that database for comparing critical exchangeable K concentrations for wheat (*Triticum aestivum*) grown on contrasting soil types is the paper by Brennan and Bell (2013). The use of such databases as repositories for data from national or international research programs would allow opportunities for collaborative approaches to the development of new soil test-crop response relationships.

8.6 Lessons Learned from Long-Term Experiments

The chapter in this book that discusses the relationship between changes in soil test values in response to K mass balance (Chap. 10), and a recent review of the lessons that long-term experiments can provide with respect to K management (Goulding et al. 2017), came to similar conclusions. While providing clear insights into the dynamics of K in soil and plant systems, long-term experiments clearly demonstrated that current soil tests targeting bioavailable K do not provide a reliable benchmark of the impact of practices on the size of the bioavailable K pool or of the long-term sustainability of K management practices. An example has also been presented in Chap. 7 (Fig. 7.6—reproduced from Hinsinger 2002), showing that despite wide variation in K balance between management strategies, there was no consistent pattern of change in exchangeable K in the soil layers monitored.

Similarly, the example provided in Fig. 8.3 in this chapter shows that even when the K status of subsoil layers (to 90 cm) was considered, and a variety of commercially available soil tests were used (exchangeable K, tetra phenyl borate-K, and nitric acid-extractable K), only a little over 50% of the soil K depletion resulting from long-term cropping could be accounted for. Such results have significant implications for the use of commercial soil testing procedures to monitor long-term changes in K fertility. A more detailed analysis of soil and crop removal data from the cropped fields depicted in Fig. 8.3 is provided by Fig. 8.5. This shows

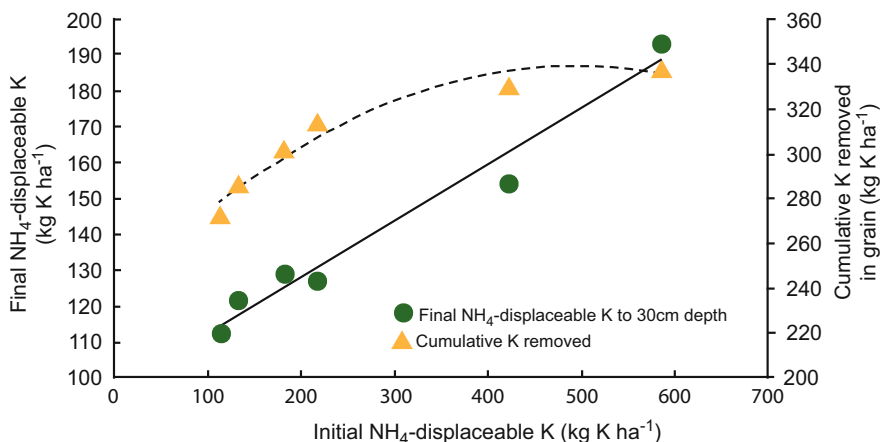


Fig. 8.5 The relationship between the initial quantum of exchangeable K (by ammonium displacement) to 30-cm depth (kg K ha^{-1}) in an Oxisol and the cumulative K removal in harvested produce over a 13-year cropping period (right) and the impact of that cumulative crop removal on the final exchangeable K remaining in the same profile layers (left). Each point represents the mean of nine replicate plots in which differing soil K concentrations were initially established by fertilizer addition

that despite a fivefold variation in initial exchangeable K (achieved through fertilizer addition), the cumulative removal of K in harvested produce only varied by a maximum of 25% over a sequence of 13 cropping seasons. However, the impact of that crop K removal on soil exchangeable K content was related strongly to the initial stocks of exchangeable K, rather than to the amount of K removed. Soils with the lowest initial exchangeable K exhibited little or no net change in exchangeable K over the cropping period, despite cumulative K removal of 270–290 kg K/ha . Conversely, soils with the highest reserves of exchangeable K recorded net changes in exchangeable K that were similar to the quantum of K removed.

These considerations are a reminder that soil testing methods targeting K pools that are bioavailable in single seasons are not always the best method of monitoring the K status of agricultural fields. The longer-term K dynamics that can occur in response to K removal, as well as the action of roots in different parts of the soil profile, also need to be considered.

8.7 Concluding Remarks

A primary consideration in the choice of analytical method and interpretation of the resulting soil test K values would seem to be the kind of cropping system for which recommendations are being made. We can define at least three scenarios from a crop demand perspective. These are: (1) very short- and short-duration crops (vegetables, cereals, and grain legumes—all with a single harvest); (2) longer season crops like

sugarcane; and (3) perennial or forage crops, where the K demand is extended over multiple years and/or multiple forage harvests per season.

If a “quick” soil test is used to predict bioavailable K for the next crop season of a short duration crop, then exchangeable K is probably the best indicator of K that the crop is likely to access, with different crops likely having different “critical ranges” that may also be dependent on the soil’s cation exchange capacity. There is not enough time for the crop rhizosphere conditions to extensively degrade minerals, and there will probably not be enough wetting and drying cycles for fixation and release to have a major impact on K availability. The major variable here is to adequately characterize readily available K in the soil layers where there is a high root density (and plant-available moisture).

For longer season crops like sugarcane, the rate of K release or replenishment over the longer time frame is likely to be more significant, as there is more time for the crop root system to access K from both surface-adsorbed and interlayer or structural K pools. In this situation, the difference between exchangeable K and non-exchangeable K (perhaps assessed by the TPB or nitric acid extractions) may correlate with crop K uptake and provide a better indication of whether or not the soil is capable of supplying K in the medium term (over several months).

The final cropping systems of interest are the multiple forage harvest or multiple crop season systems (e.g., lucerne/alfalfa), where demand is high and persistent over an extended period of time (years). Here, the more slowly available K (interlayer and structural pools) becomes critically important for the sustained removal and replenishment of plant-available K. Exhaustive cut-and-remove pot trials are extreme examples of this, because inevitably there is a restricted soil volume as well as a very high root density, in addition to the high and prolonged K demand. In these situations, the rate of release/replenishment of slowly available K pools quickly becomes the dominant factor in determining fertilizer K responsiveness.

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