Range Management and Agroforestry 45 (1) : 82-89, 2024
ISSN 0971-2070 (Print); 2249-5231 (Online)
https://doi.org/10.59515/rma.2024.v45.i1.11

Research article

Effect of potassic fertilization on yield of fodder sorghum-sudan grass hybrid and selection of extractants for determination of plant potassium availability

Subhadip Paul, Mandira Barman[*] and Debarup Das

ICAR-Indian Agricultural Research Institute, New Delhi-110012, India
[*]Corresponding author email: mandira.ssaciari@gmail.com

Received: 24th May, 2023 Accepted: 11th August, 2023

Abstract

The current study was carried out to assess the effect of potassium (K) fertilization on K-uptake and yield of fodder sorghum-sudan grass hybrid and to choose extractant(s), delineating the K-availability for routine soil testing method. Hybrid sorghum-Sudan grasses were grown in three different soils (red, alluvial, and black) with 100, 50, and 0% recommended K-doses for five seasons. Seven extractants, namely, cold H_2SO_4, Mehlich-1, 0.1 N CH_3COONa, 1 N CH_3COONH_4 (pH 7), 0.1 N $BaCl_2$, and sodium tetraphenylborate (NaTPB) with 5 and 15 minutes of contact times, were evaluated for elucidating forage K-availability. Results have revealed that biomass yields from all soils were higher ($p < 0.05$) in K-100% than in K-0%; whereas NaTPB (5 minutes) and ammonium acetate were found as better extractants for the determination of forage K-availability.

Keywords: Ammonium acetate, Sodium tetraphenylborate, Sorghum-Sudan grass hybrid

Introduction

With the pressure from India's growing population and its demand for food, an expansion of agricultural land has been extensively observed in the past few decades with the abatement of pasture lands and areas under fodder cultivation. The country has nearly 20% of the world's livestock population that has been facing ~ 36% shortage of green fodder (Singh *et al*., 2022). Green fodder is an important nourishment to the milch breeds of cattle (Mahanta *et al*., 2020). As India's share in global milk production has risen to 21%, this supply gap of green fodder should be maintained at a minimum (GOI, 2023). The government of India already subsidized the beneficiaries for setting up fodder value addition units under the National Livestock Mission Scheme (GOI, 2022). However, the area under cultivated fodder accounted for only 4% of the total cultivated area in this country (Singh *et al*., 2022).

Due to quick growth habits and palatable nature, fodder sorghum, *i.e.*, forage sorghum or Sudan grass or sorghum-Sudan grass hybrid, is considered nutritious green fodder (Prajapati *et al*., 2022). However, fodder sorghum is a heavy feeder of soil nutrients. Care should be taken to maximize its production by optimizing nutrient management. In this aspect, nitrogen (N), phosphorus (P), and micronutrients were given priority by many researchers (Dhar *et al*., 2003; Dixit *et al*., 2014; Prajapati *et al*., 2022). Very little effort was made to understand the effect of external potassium (K) application on the yield of fodder sorghum (Tokas *et al*., 2021). This is because there has been a common assumption that Indian soils are dominated by K-rich micaceous clay minerals (Sanyal 2014). Besides, K-application in Indian agriculture has long been dependent upon imports which increased the price of K-fertilizers (Sanyal, 2014; Das *et al*., 2022). Thus, external K-application was ignored in maximum cases of crop production, resulting in the depletion of non-exchangeable soil-K through mining (Das *et al*., 2019; Das *et al*., 2022). Further indiscriminate use of N- and P-fertilizers aggravated this situation. As the plant available-K pools are in dynamic equilibrium with non-exchangeable-K, fixed within the interlayers of 2:1 clay minerals, the K-mining might go unnoticed. However, alteration of these minerals could occur in the long run and this can render future K-fertilization ineffective due to K-fixation within those vacant sites (Das *et al*., 2019, 2022). India is dominated by alluvial soil, followed by red and black soils (Das *et al*., 2019; Datta *et al*., 2020; Das *et al*., 2022). These soils have varying chemical and mineralogical compositions. Therefore, the K-supplying power of these soils was found to be different (Das *et al*., 2019, 2022; Datta *et al*., 2020). Though 1 N ammonium acetate was reported to provide a good estimate of the plant K-availability, the method was proven inadequate in some cases, especially when there is an abundance of K-fixing 2:1 clay minerals (Hanway and Heidel, 1952; Bilias and Barbayiannis, 2016). Hence, for a comprehensive evaluation of K-availability to fodder sorghum in Indian soil, suitable extractants must be assessed based on routine soil testing methods. Thus, the objectives of the experiment were to evaluate (i) the effect of graded doses of K-fertilization on K-uptake and yield of fodder sorghum-Sudan grass hybrid and (ii) different extractants befitting the forage K-availability for the routine soil test.

Materials and Methods

***Experimental sites*:** Three major soil types (15 cm depth) of India were sampled for this study to take the diverse soil physicochemical properties into account. The alluvial soil, which belonged to Typic Haplustept, was taken from the ICAR-Indian Agricultural Research Institute, New Delhi with a latitude 28° 38′ N and a longitude 77° 10′ E. Red soil represented Typic Haplustalf and was collected from Hazaribagh, Jharkhand with latitude 23° 57′ N and longitude 85° 22′ E. The black soil was sampled from Bhopal, Madhya Pradesh (23° 18′ N latitude and 77° 24′ E longitude) and it represented the Typic Haplustert.

***Physicochemical properties of the initial sampled soils*:** The soil reactions of alluvial and black soils were slightly alkaline in nature, i.e., pH 7.6-7.8; while the red soil was acidic (pH 5.3). All soils possessed very low salt concentrations (range of electrical conductivity 0.1– 0.5 dS m^{-1}). Black soil had a higher amount of organic carbon (~ 0.8%); whereas the contents were found low in the case of red (< 0.5%) and alluvial soils (< 0.5%) (Walkley and Black, 1934). As per the method proposed by Sumner and Miller (1996), the cation exchange capacity (CEC) of black was found to be very high (~ 49 cmol kg^{-1}) in comparison to red (~ 13 cmol kg^{-1}) and alluvial soils (~ 15 cmol kg^{-1}). Available-K was very high for all soils as determined by 1 N CH_3COONH_4 at pH 7 (Hanway and Heidel, 1952). Both alluvial and red soils contained 136 mg kg^{-1} soil and black soil contained 250 mg kg^{-1} soil. Previous K-fertilization during crop cultivation was the reason behind the higher availability of plant-K in these soils. Bouyoucos's (1962) hydrometer was used to find out soil texture. Black and red soils had clay textures with higher clay content in the former soil. Alluvial soil had a sandy clay loam texture with lower clay content than the other two soils.

***Pot experiment*:** A total of 27 pots (3 soils, 3 K-doses, and 3 replications) were stacked with 4 kg soil after screening with a 2 mm sieve. Each pot was treated with equal doses of nitrogen (100 kg N ha^{-1}) and phosphate (P_2O_5) fertilizers (80 kg ha^{-1}). Then, three graded doses of K_2O were added as follows:

K-100%: Recommended dose of K-fertilization (40 kg K_2O ha^{-1}), *i.e.*, 60 mg K pot^{-1}, K-50%: 50% of the recommended dose of K-fertilization, i.e., 30 mg K pot^{-1}, and K-0%: No external K-fertilization or control.

The sorghum-sudan grass hybrids (*Sorghum bicolor* × *Sorghum bicolor var. sudanese*) were grown for five seasons in these pots. A total of seven plants were nurtured for 35 days, *i.e.*, before flower initiation, in each cycle and were harvested thereafter. After the completion of each cycle, similar doses of N and P_2O_5 and graded doses of K_2O were applied (except K-0%) to their respective treatments, and seeds were sown. Cutting and regrowth were avoided. Only single distilled water was used for irrigation to exclude additional K-input in the pots. The aboveground harvested forages were dried at 65 ± 2°C. The below-ground portions or roots were retained in the soils during the study period. Otherwise, the K balance would not be possible to maintain. The roots were cut into small pieces and mixed thoroughly within their respective pots. The oven-dried biomasses of forage were weighed to get the fodder yield. From these, 1 g of dry samples was digested with an acid mixture of HNO_3: $HClO_4$ (3:1) and heated in a hot plate at 180°C until the solution color changed to white. The K-content in biomass was determined in the flame photometer. The dry biomass weights and K-uptakes over five seasons were averaged for every replicate of each treatment, separately for every soil.

***Soil potassium release with different extractants*:** Different extractants were evaluated for routine analysis of plant available-K. Readings were taken in the initial soils and soils after completion of cropping for five seasons. Soil sample (5 g) was shaken for 30 minutes with Mehlich-1 (0.05 N HCl + 0.025 N H_2SO_4), 0.1 N CH_3COONa (NaOAc), 0.1 N $BaCl_2$, and 1 N CH_3COONH_4 at pH 7 (NH_4OAc), separately and filtered thereafter (Hanway and Heidel, 1952; Mehlich, 1973; Page *et al*., 1982; Pal *et al*., 2001). For K-extraction with cold H_2SO_4, 10 g soil was mixed thoroughly for 30 minutes with 25 mL distilled water and 1-mL concentrated H_2SO_4. The filtrate was collected in 100 mL volumetric flask and the volume was made up by repeated washing with 0.1 N H_2SO_4 (Page *et al*., 1982). About 0.5 g soil was incubated for 5 and 15 minutes, separately, with 0.2 M sodium tetraphenylborate (NaTPB) + 1.7 M NaCl + 0.01 M ethylene diamine tetra-acetic acid (EDTA) reagent. Then, 25 mL of 0.14 M $CuCl_2$ + 0.5 M NH_4Cl was added to the system to stop the reaction. The system was heated in the water bath at 110°C for 60 minutes. After that, these systems were cooled and volume was made up to 50 mL with distilled water. About 20 mL of the suspension was centrifuged for 10 minutes at $2500 \times g$ after acidifying the suspension with 6 N HCl (Cox *et al*., 1999; Wang *et al*., 2016). All the K-readings were taken with the flame photometer. The sensitivity of extractants over K-released from graded doses of fertilization after 5 seasons of cropping was evaluated for each soil with respect to K-released from initial soil samples and was calculated as follows:

$$\text{Variation (\%)} = \frac{(\text{Extracted-K from treatments} - \text{Extracted-K from initial soil}) \times 100}{\text{Extracted-K from initial soil}}$$

***Statistical analysis*:** The analysis of variance (ANOVA; $p < 0.05$) was carried out in a completely randomized design using R (4.2). The honest significant difference (HSD; $p < 0.05$) test of Tukey was done to compare the mean values. Pearson's correlation coefficients (r; $p < 0.05$) were determined between K-released by different extractants in the initial soil samples and average (over 5 seasons) forage K-uptake from K-0% treatments and between forage K-uptake and yield, averaged over 5 seasons, using R.

Results and Discussion

***Average yield and potassium uptake by forage*:** In red and alluvial soils, the average yields had significantly ($p < 0.05$) increased in K-100% over K-50% and K-0% treatments (Fig 1b). However, yields from K-50% and K-100% in black soil were found at par with each other but greater ($p < 0.05$) than K-0% (Fig 1a). The red and black soils showed comparatively ($P < 0.05$) higher yields than alluvial soil over the different K-doses (Fig 1b).

Black soil showed an increase in average K-uptake with a concomitant increase in K-doses (Fig 2a). In the case of alluvial soil, the average K-uptake by sorghum-Sudan grass of K-100% was found to be significantly ($p < 0.05$) higher than the K-0% treatment. The average K-uptake by K-50% treatment was statistically at par with both K-100% and K0% in alluvial soil; whereas the forage K-uptakes in K-50% and K-0% treatments of red soil showed a lower ($p < 0.05$) K-uptake than K-100% (Fig 2a). Regardless of the different K-doses, average forage K-uptake followed a decreasing order: black soil > red soil > alluvial soil (Fig 2b). The reason behind the higher average yields and average K-uptakes in black and red soils was due to the presence of higher clay combined with higher plant available-K contents in these soils.

Sanyal (2014) and Datta *et al*. (2020) explained that as alluvial soils have higher amounts of vermiculite and illite, the K-availability became lower due to fixation. Thus, even after applying a high amount of K (K-100%), the average forage K-uptake from alluvial soil remained lower than in other soils. On the other hand, black and red soils were dominated by smectite and kaolinite, respectively, other than illite (Das *et al*., 2019; Datta *et al*., 2020;). Hence, fixations of applied-K were comparatively lesser than alluvial soil; while their biomass yields were higher than the same.

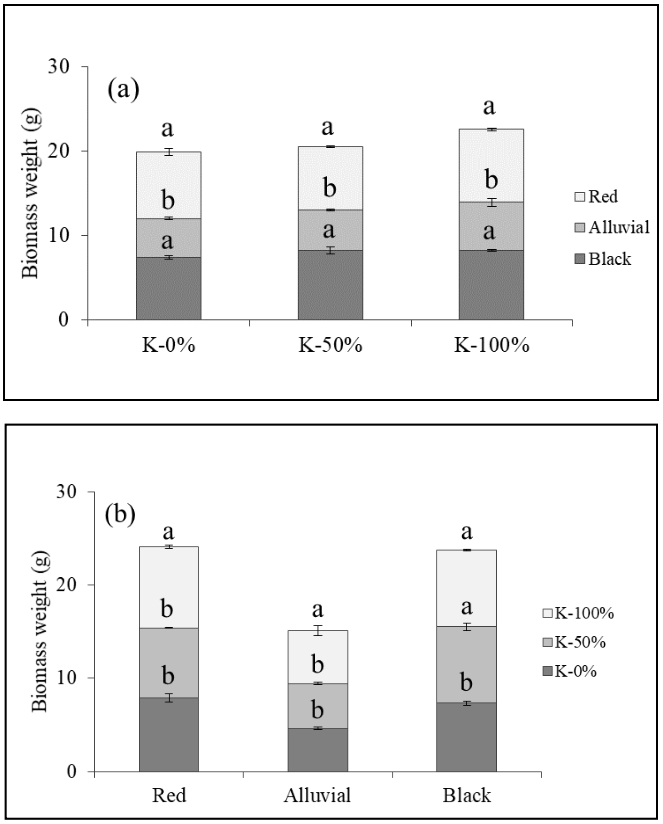

Fig 1. Comparison of average sorghum-sudan grass hybrid yields (g) over five cropping seasons (a) among soils for a particular K-dose and (b) among K-doses for each soil. Bars represent standard deviations (replication = 3). Different letters in the segments of each column are significantly ($p < 0.05$) different mean values as per Tukey's HSD test performed for each dose of potassium

A strong positive correlation ($r = 0.83$, $p < 0.05$) between average K-uptake and average yield signified that with an increase in K-uptake dry biomass weight of sorghum-Sudan grass hybrid also increased. The sorghum-Sudan grass is a heavy feeder of soil-K and thus, the yield was very much dependent upon the forage K-uptake (Prajapati *et al*., 2022). Therefore, adequate K-nutrition should be provided to get better fodder yield. Karforma *et al*. (2016) found higher rainfed fodder maize yield under optimum K supply in an integrated nutrient management practice. Chaudhary *et al*. (2016) also found that higher K fertilization ensured fodder yield than control. Similarly, higher yield and nutritive value addition were found by Choudhary *et al*. (2019) under integrated K management along with sulfur fertilization and crop residue incorporation.

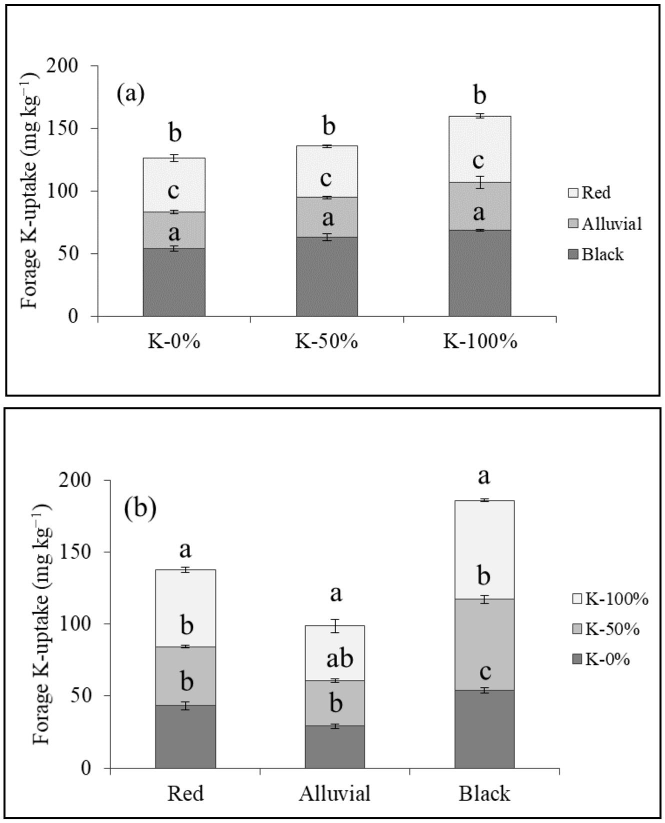

Fig 2. Comparison of average potassium (K) uptakes (mg kg^{-1}) by sorghum-sudan grass hybrid over five cropping seasons (a) among soils for a particular K-dose, and (b) among K-doses for each soil. Bars represent standard deviations (replication = 3). Different letters in the segments of each column are significantly (p <0.05) different mean values as per Tukey's HSD test performed for each dose of potassium

Comparison of different extractants for soil potassium release: The K-released from three soils (initial soils and soils after five cropping seasons with graded K-doses) by seven extractants were recorded (Table 1). From all soils, NaTPB (15 minutes) extracted the highest amounts of soil-K. Potassium extracted by H_2SO_4 was also statistically at par with NaTPB (15 minutes) in K-0% and K-50% treatments of alluvial soil. The NH_4OAc, NaTPB (5 minutes), Mehlich-1, and H_2SO_4 also removed comparatively higher (p <0.05) soil-K than $BaCl_2$ and NaOAc. All these extractants followed different ways of drawing out soil-K. Mehlich-1 and cold H_2SO_4 acidified the soil, increasing the dissolution of clay minerals near edge and wedge positions (Najafi-Ghiri *et al*., 2023). Acetate of Na^+ could only replace K^+ (hydrated radius: 0.331 nm) from the planar sites of clay minerals due to its bigger hydrated size (0.358 nm) that reduced the accessibility of Na^+ into interlayers (Dhillon *et al*., 1989; Jalali, 2006). Effective electrostatic attraction force between negatively charged clay particles and hydrated Na^+ also made it less effective against K-exchange from planar positions. Similarly, NH_4OAc had the capacity to replace more K^+ than NaOAc because it is a dipole with 4 H^+ attached to the four corners of NH_4^+-tetrahedron, possessing lower hydration energy than Na^+ (Pironon *et al*., 2003). Therefore, it could block the wedge zone of 2:1 clay minerals, rendering only exchangeable and solution K-pools to be available to forage (Martin and Sparks, 1983; Dhillon *et al*., 1989; Pironon *et al*., 2003; Jalali, 2006). The Ba^{2+} held both lower hydration energy (- 308 kcal mol^{-1}) and divalent charge than monovalent Na^+ (- 95 kcal mol^{-1}) (Rodriguez-Cruz *et al*., 1999; Teppen and Miller, 2006). Thus, the K-replacing tendency of $BaCl_2$ was found to be superior to NaOAc (Table 1). Nevertheless, NaTPB formed complexes with K^+ in soil solution and from the exchangeable sites, allowing the further release of interlayer-K to enter into solution or exchangeable positions through diffusion as well as exchange processes (Cox *et al*., 1999; Wang *et al*., 2016). It actually mimicked the K-uptake by the forage root system. The more contact time would be given, the more amount of K^+ would be drawn out of the soil (Wang *et al*., 2016). Hence, a contact time of 15 minutes allowed higher extraction of K^+ by NaTPB over 5 minute period (Table 1). There were certain depressions in K-release by all extractants from the soils of K-0% treatments than their respective initial samples (Tables 1 and 2). This inferred that soil K-reserves failed to maintain the plant-K availability after continuous removal from the control pots by sorghum-Sudan grass hybrid. The result had also been reflected in the forage K-uptake and yield, averaged over five seasons, from the K-0% pots (Figs 1a and 2a).

The percent variation in K-released by an extractant over graded K-doses reflected the detection of minute change in K-release with response to external K-fertilization (Table 2). Negative values indicated that lesser amount of K-extraction relative to initial soils. In the case of NaTPB (5 minutes), NaTPB (15 minutes), and NH_4OAc, significant variations (p < 0.05) were observed among graded-K treatments of all soils.

Except for K extracted by Mehlich-1 from black soil, all other extractants showed negative variations in K-0% (Table 2). The positive variation in K extracted by Mehlich-1 from K-0% treatment of black soil suggested that planner sites of smectite-rich black soil retain more K in the exchangeable pool, which the acid-based extractants can easily access. The remaining positive variations in K-50% and K-100% inferred that the amount of added K has a direct influence on plant K availability. Thus, NaOAc extracted a higher proportion of planner K which got built up after external K additions. These planner K were more prone to acid extraction, i.e., H_2SO_4 and Mehlich-1, than neutral salts and NaTPB. However, these K might not be able to indicate plant K availability fully, as the cropping cycles were reported to deplete added K along with the native K from any soil during its life

Table 1. Soil potassium (K) release by different extractants (mean ± standard deviation)

Extractant	**Initial**	**K-0%**	**K-50%**	**K-100%**
	(mg kg^{-1})	**(mg kg^{-1})**	**(mg kg^{-1})**	**(mg kg^{-1})**
Red soil				
$BaCl_2$	19.4 ± 1.38^{e}	14.8 ± 0.78^{e}	15.6 ± 1.06^{e}	18.1 ± 0.75^{e}
H_2SO_4	63.4 ± 1.75^{d}	58.3 ± 1.76^{cd}	65.4 ± 2.12^{d}	72.2 ± 2.33^{d}
Mehlich-1	51.9 ± 2.36^{d}	48 ± 2.72^{d}	58.6 ± 3.55^{d}	64.8 ± 2.96^{d}
NaOAc	10.6 ± 0.87^{e}	8.2 ± 0.79^{e}	10.2 ± 0.62^{e}	12.5 ± 0.61^{e}
NaTPB (15 minutes)	476 ± 18.33^{a}	328 ± 10^{a}	365.3 ± 23.35^{a}	426 ± 13.11^{a}
NaTPB (5 minutes)	205.3 ± 8.32^{b}	85.3 ± 12.05^{bc}	127.3 ± 13.31^{b}	161.3 ± 10.26^{b}
NH_4OAc	135.9 ± 1.18^{c}	91.5 ± 4.79^{b}	105.5 ± 4^{c}	130.5 ± 8.93^{c}
Alluvial soil				
$BaCl_2$	61.4 ± 0.64^{d}	44.7 ± 2.17^{e}	49.9 ± 3.27^{d}	58.4 ± 1.81^{e}
H_2SO_4	191.4 ± 3.92^{b}	182 ± 5.79^{a}	197.2 ± 3.85^{a}	209.5 ± 5.7^{b}
Mehlich-1	134.3 ± 5.55^{c}	130.9 ± 3.17^{b}	148 ± 9.27^{b}	161.3 ± 14.77^{c}
NaOAc	26.8 ± 1.61^{e}	24.7 ± 0.62^{f}	31.1 ± 0.65^{d}	32.4 ± 1.02^{f}
NaTPB (15 minutes)	332 ± 9.16^{a}	164 ± 14^{a}	210.6 ± 14.18^{a}	292.6 ± 13.01^{a}
NaTPB (5 minutes)	176 ± 15.09^{b}	80 ± 4^{d}	104 ± 7.21^{c}	135.3 ± 9.01^{d}
NH_4OAc	131.6 ± 0.77^{c}	100 ± 5.89^{c}	109.9 ± 4.43^{c}	138.1 ± 5.05^{cd}
Black soil				
$BaCl_2$	28.3 ± 2.3^{e}	23.3 ± 0.88^{d}	23.6 ± 0.93^{e}	27.9 ± 0.97^{e}
H_2SO_4	195.5 ± 6.97^{c}	184 ± 2.3^{b}	195.3 ± 4.39^{c}	202.4 ± 0.9^{b}
Mehlich-1	126.3 ± 5.61^{d}	126.9 ± 2.87^{c}	140.7 ± 5.5^{d}	143.6 ± 7.07^{d}
NaOAc	10.4 ± 0.07^{e}	9.9 ± 0.7^{d}	11.1 ± 0.95^{e}	11.3 ± 0.7^{f}
NaTPB (15 minutes)	414.6 ± 4.16^{a}	212.6 ± 7.02^{a}	232 ± 4^{a}	242.6 ± 3.05^{a}
NaTPB (5 minutes)	209.3 ± 18.03^{c}	114 ± 9.16^{c}	142 ± 6^{d}	165.3 ± 8.32^{c}
NH_4OAc	251.3 ± 3.16^{b}	194.2 ± 6.63^{b}	214 ± 7.44^{b}	249.2 ± 8.63^{a}

Superscripts in each column for each soil denote significantly ($P<0.05$) different means as per Tukey's HSD test. NaOAc, 0.1 N CH_3COONa; NaTPB, sodium tetraphenyl borate; NH_4OAc, 1 N CH_3COONH_4

cycle (Wang *et al.*, 2016). Cox *et al.* (1999) also reported that K^+ extracted from soils grown with ryegrass by NaTPB (both 5 and 15 minutes) were sensitive to K-management practices. They also reported that soil-K extraction by NH_4OAc was also responsive to the K-fertility treatments but less efficient than the NaTPB method. There were no significant variations in K-released by $BaCl_2$, H_2SO_4, Mehlich-1, and NaOAc over graded-K treatments in black soils. The black soil contained swelling-type 2:1 minerals, which opened up the interlayers to facilitate K-exchange easily (Datta *et al.*, 2020). However, changes in variations could be observed for these extractants in red and alluvial soils. Except for K-100% treatment in alluvial soil of NH_4OAc, a lesser amount of K-extraction occurred by $BaCl_2$, NaTPB (5 minutes), NaTPB (15 minutes), and NH_4OAc from K-0%, K-50%, and K-100% treatments as compared to the initial soils; whereas, comparatively more K was extracted by Mehlich-1, H_2SO_4, and NaOAc in K-50% and K-100% treatments than initial samples (except K-50% of NaOAc). These two acidic extractants showed significantly higher ($p<0.05$) K-release power than NaOAc because the dissolution of mineral structure might have released exchangeable-K and some of the interlayer-K into the solution (Najafi-Ghiri *et al.*, 2023). Whereas, only adsorbed-K, being high in K-treated pots, was released by NaOAc with respect to initial samples (Jalali, 2006).

***Correlation between extractants and crop potassium uptake*:** As external K-doses were applied continuously in K-50% and K-100% treatments to supply K to the forage crops, the correlations between K-released by various extractants from initial soils and average forage K-uptake from these two treatments were avoided. It was clear that 1 N NH_4OAc ($r = 0.83$, $p<0.05$) and NaTPB (5

Table 2. Sensitivity of extractants over varying doses of soil potassium (K) in each soil (mean ± standard deviation)

Extractant	**Soil**	**Variation (%) in respect to initial soil**		
		K-0%	**K-50%**	**K-100%**
$BaCl_2$	Red	− 22.9 ± 9.44^{a}	− 19.3 ± 1.81^{a}	− 6.2 ± 10.42a
	Alluvial	− 27.1 ± 4.31^{b}	− 18.7 ± 5.78^{b}	− 4.8 ± 3.9$_{a}$
	Black	− 17.2 ± 6.8^{a}	− 16.1 ± 8.64^{a}	− 1 ± 7.72^{a}
H_2SO_4	Red	− 8.1 ± 2.38^{b}	3.2 ± 6.17^{ab}	13.8 ± 5.71^{a}
	Alluvial	− 4.9 ± 2.75^{b}	3 ± 1.99^{ab}	9.4 ± 5.06^{a}
	Black	− 5.7 ± 3.92^{a}	0 ± 3.4^{a}	3.6 ± 4.15^{a}
Mehlich-1	Red	− 7.2 ± 9.03^{b}	12.8 ± 3.02^{ab}	25.1 ± 11.49^{a}
	Alluvial	− 2.4 ± 4.32^{a}	10.2 ± 7.76^{a}	20.3 ± 15.01^{a}
	Black	0.5 ± 2.61^{a}	11.4 ± 2.28^{a}	14 ± 10.53^{a}
NaOAc	Red	− 22 ± 1.63^{c}	− 3.1 ± 2.17^{b}	19 ± 7.14^{a}
	Alluvial	− 7.6 ± 3.99^{b}	16.2 ± 4.4^{a}	21.3 ± 3.54^{a}
	Black	− 5.2 ± 7.04^{a}	6.2 ± 9.37^{a}	8.4 ± 5.97^{a}
NaTPB (15 minutes)	Red	− 30.9 ± 4.24^{b}	− 23.2 ± 4.35^{b}	− 10.3 ± 6.14^{a}
	Alluvial	− 50.5 ± 5.13^{c}	− 36.4 ± 5.41^{b}	− 11.8 ± 1.55^{a}
	Black	− 48.6 ± 2.2^{b}	− 44 ± 0.45^{a}	− 41.4 ± 0.33^{a}
NaTPB (5 minutes)	Red	− 58.4 ± 5.44^{b}	− 37.8 ± 7.47^{a}	− 21.2 ± 6.96^{a}
	Alluvial	− 54.4 ± 3.02^{b}	− 40.3 ± 9.42^{b}	− 22.9 ± 4.88^{a}
	Black	− 45.3 ± 5.26^{b}	− 31.6 ± 8.71^{ab}	− 20.4 ± 10.63^{a}
NH_4OAc	Red	− 32.5 ± 4.11^{b}	− 22.3 ± 2.98^{b}	− 3.9 ± 7.03^{a}
	Alluvial	− 24 ± 4.03^{b}	− 16.5 ± 2.92^{b}	4.8 ± 3.23^{a}
	Black	− 22.7 ± 1.67^{b}	− 14.8 ± 2.95^{b}	− 0.7 ± 4.5^{a}

Superscripts in each row for each soil denote significantly (p <0.05) different means as per Tukey's HSD test. NaOAc, 0.1 N CH_3COONa; NaTPB, sodium tetraphenylborate; NH_4OAc, 1 N CH_3COONH_4

Table 3. Pearson's correlation coefficient (*r*) among potassium (K) released with various extractants and average forage K-uptake from three soils without K-application (K-0%)

r	**K-uptake**	**$BaCl_2$**	**NaOAc**	**Mehlich-1**	**H_2SO_4**	**NH_4OAc**	**NaTPB (5 minutes)**	**NaTPB (15 minutes)**
K-uptake	1*							
$BaCl_2$	− 0.78*	1*						
NaOAc	− 0.88*	0.97*	1*					
Mehlich-1	− 0.14^{n}	0.72*	0.57^{n}	1*				
H_2SO_4	− 0.05^{n}	0.64^{n}	0.46^{n}	0.98*	1*			
NH_4OAc	0.83*	− 0.34^{n}	− 0.53^{n}	0.39*	0.5^{n}	1*		
NaTPB (5 minutes)	0.79*	− 0.76*	− 0.76*	− 0.32^{n}	− 0.32^{n}	0.48^{n}	1*	
NaTPB (15 minutes)	0.6^{n}	− 0.96*	− 0.88*	− 0.86*	− 0.79*	0.11^{n}	0.62^{n}	1*

‘’ indicates significant r at p <0.05; ‘^{n}’ indicates nonsignificant r at p >0.05*

minutes) ($r = 0.79$, $p < 0.05$) could extensively be useful to evaluate soil K-availability to the sorghum-sudan grass hybrid (Table 3).

Though K-extracted by $BaCl_2$ and NaOAc possessed higher correlations ($r = -0.78$ and -0.88, respectively at $p < 0.05$) with average forage K-uptakes, the negative values did not clarify whether the low plant-K availability would enhance forage K-uptake. Our results were at par with Cox *et al*. (1999) who found that plant available-K in ryegrass was strongly associated with NH_4OAc and NaTPB (5 minutes) extractable K-contents. Bilias and Barbayiannis (2016) have also found that K-uptake by winter wheat in each cropping season positively correlated with K-extracted by NH_4OAc (30 minutes) and NaTPB (5 minutes).

Conclusion

Potassium application at optimum dose is necessary to obtain a higher yield of fodder sorghum-sudan grass hybrid. Correlation with average forage potassium uptake revealed that potassium extracted by sodium tetraphenylborate with a contact time of 5 minutes and neutral normal ammonium acetate could be used as the two best extractants for the determination of potassium availability to sorghum-sudan grass hybrid.

Acknowledgment

The authors would like to thank the Director of ICAR-Indian Agricultural Research Institute, New Delhi, for providing the required facilities to conduct the experiment.

References

Bilias, F. and N. Barbayiannis. 2016. Evaluation of sodium tetraphenyl boron ($NaBPh_4$) as a soil test of potassium availability. *Archives of Agronomy and Soil Science* 63: 468-476.

Bouyoucos, G. J. 1962. Hydrometer method improved for making particle size analyses of soils. *Agronomy Journal* 54: 464-465.

Chaudhary, D. P., A. Kumar, R. Kumar, A. Singode, G. Mukri, R. P. Sah, U. S. Tiwana and B. Kumar. 2016. Evaluation of normal and specialty corn for fodder yield and quality traits. *Range Management and Agroforestry* 37: 79-83.

Choudhary, M., K. S. Rana and P. Kumar. 2019. Nutritive value of pearl millet stover as influenced by tillage, crop residue and sulphur fertilization. *Range Management and Agroforestry* 40: 150-155.

Cox, A. E., B. C. Joern, S. M. Brouder and D. Gao. 1999. Plant available potassium assessment with a modified sodium tetraphenylboron method. *Soil Science Society of America Journal* 63: 902-911.

Das, D., B. S. Dwivedi, S. P. Datta, S. C. Datta, M. C. Meena, B. K. Agarwal, D. K. Shahi, M. Singh, D. Chakraborty and S. Jaggi. 2019. Potassium supplying capacity of a red soil from eastern India after forty-two years of continuous cropping and fertilization. *Geoderma* 341: 76-92.

Das, D., J. Sahoo, M. B. Raza, M. Barman and R. Das. 2022. Ongoing soil potassium depletion under intensive cropping in India and probable mitigation strategies- a review. *Agronomy for Sustainable Development* 42: 1-26.

Datta, S. C., S. K. Ghosh and D. Das. 2020. Soil mineralogy and clay minerals. In: B. B. Mishra (ed). *The Soils of India, World Soils Book Series*, Springer. Cham. pp. 109-127.

Dhar, S., S. D. Gupta, S. N. Tripath and S. K. Rai. 2003. Response of fodder sorghum varieties to nitrogen and sowing time. *Range Management and Agroforestry* 24: 132-134.

Dhillon, S. K., P. S. Sidhu and R. C. Bansal. 1989. Release of potassium from some benchmark soils of India. *Journal of Soil Science* 40: 783-797.

Dixit, A. K., S. Kumar, A. K. Rai and D. R. Palsaniya. 2014. Productivity and profitability of fodder sorghum + cowpea–chickpea cropping system as influenced by organic manure, phosphorus and sulphur application in central India. *Range Management and Agroforestry* 35: 66-72.

GOI. 2022. Scheme for animal feed producers. Press Information Bureau, Ministry of Fisheries, Animal Husbandry and Dairying, Government of India, New Delhi. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1795557 (accessed on Apr. 15, 2023)

GOI. 2023. Union Home Minister and Minister of Cooperation, Shri Amit Shah attends the 49th Dairy Industry Conference organized by Indian Dairy Association as chief guest at Gandhinagar, Gujrat today. Press Information Bureau, Ministry of Cooperation, Government of India, New Delhi. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1908343 (accessed on Mar. 27, 2023)

Hanway, J. J. and H. Heidel. 1952. Soil analysis methods as used in Iowa State College Soil Testing Laboratory. *Iowa Agriculture* 57: 1-13.

Jalali, M. 2006. Kinetics of non-exchangeable potassium release and availability in some calcareous soils of western Iran. *Geoderma* 135: 63-71.

Karforma, J., M. Ghosh, D. C. Ghosh, S. Mandal and P. K. Ghosh. 2016. Effect of integrated nutrient management on performance of rainfed fodder maize-rapeseed cropping system. *Range Management and Agroforestry* 37: 214-221.

Mahanta, S.K., S.C. Garcia and M.R. Islam. 2020. Forage based feeding systems of dairy animals: issues, limitations and strategies. *Range Management and Agroforestry* 41: 188-199.

Martin, H. W. and D. L. Sparks. 1983. Kinetics of non-exchangeable potassium release from two coastal plain soils. *Soil Science Society of America Journal* 47: 883-887.

Mehlich, A. 1973. Uniformity of soil test results as influenced by volume weight. *Communications in Soil Science and Plant Analysis* 4: 475-486.

Najafi-Ghiri, M., H. R. Boostani and A. G. Hardie. 2023. Release of potassium from some heated calcareous soils to different solutions. *Archives of Agronomy and Soil Science* 69: 90-103.

Page, A. L., R. H. Miller and D. R. Keeney. 1982. *Methods of Soil Analysis (Part II): Chemical and Microbiological Properties,* Vol. 2. Agronomy Society of America, Madison, Wisconsin.

Pal, D. K., P. Srivastava, S. L. Durge and T. Bhattacharyya. 2001. Role of weathering of fine-grained micas in potassium management of Indian soils. *Applied Clay Science* 20: 39-52.

Pironon, J., M. Pelletier, P. De Donato and R. Mosser-Ruck. 2003. Characterization of smectite and illite by FTIR spectroscopy of interlayer NH_4^+ cations. *Clay Minerals* 38: 201–211.

Prajapati, D. R., N. S. Thakur, R. P. Gunaga, V. R. Patel, L. Mahatma and D. P. Patel. 2022. *Melia dubia* tree spacing influence growth, yield and proximate principles of *Sorghum bicolor x Sorghum bicolor* var. *sudanese* and soil microbial status. *Range Management and Agroforestry* 43: 283-291.

Rodriguez-Cruz, S. E., R. A. Jockusch and E. R. Williams. 1999. Hydration energies and structures of alkaline earth metal ions, M^{2+} $(H_2O)_n$, n= 5–7, M= Mg, Ca, Sr, and Ba. *Journal of the American Chemical Society* 121: 8898-8906.

Sanyal, S. K. 2014. Potassium-the neglected major plant nutrient in soil-crop management practices. *Journal of the Indian Society of Soil Science* 62(Supplement): S117-S130.

Singh, D. N., J. S. Bohra, V. Tyagi, T. Singh, T. R. Banjara and G. Gupta. 2022. A review of India's fodder production status and opportunities. *Grass Forage Science* 77: 1-10.

Sumner, M. E. and P. M. Miller. 1996. Cation exchange capacity and exchange coefficient. In: D. L. Sparks, A. L. Page, P. A. Helmke, R. H. Loeppert, P. N. Soltanpour, M. A. Tabatabai, C. T. Johnston and M. E. Sumner (eds). *Methods of Soil Analysis (Part III): Chemical Methods,* Vol. 5. Soil Science Society of America, Madison, Wisconsin. pp. 1201-1229.

Teppen, B. J. and D. M. Miller. 2006. Hydration energy determines isovalent cation exchange selectivity by clay minerals. *Soil Science Society of America Journal* 70: 31-40.

Tokas, J., H. Punia, A. Malik, S. Sangwan, S. Devi and S. Malik. 2021. Growth performance, nutritional status, forage yield and photosynthetic use efficiency of sorghum [*Sorghum bicolor* (L.) Moench] under salt stress. *Range Management and Agroforestry* 42: 59-70.

Walkley, A. and I. A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science* 37: 29-38.

Wang, H. Y., W. Cheng, T. Li, Z. H. Jianmin and C. H. Xiaoqin. 2016. Can non-exchangeable potassium be differentiated from structural potassium in soils? *Pedosphere* 26: 206-215.