Measuring potassium uptake and growth response of annual ryegrass at multiple K rates in K-fixing and non-K-fixing soils

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INTRODUCTION

The fixation of potassium in non-exchangeable forms has been identified as a source of concern for soil fertility management in parts of the San Joaquin Valley of central California. The potential for K fixation in these soils has been linked to vermiculite in the silt and fine sand fraction of granitic alluvium[1]. Applying K to K-fixing soils at rates equivalent to measured K fixation potential values resulted in much of the K being removed from ammonium acetate-exchangeable K (XK) pool within 24 hours, but without satiating the K-fixing capacity of the soils[2]. Increasing K additions resulted in increasing quantities of K fixed.

The sodium tetraphenylboron method of K extraction (TPB-K), developed by Scott et al.[3] and refined by Cox et al.[4] has been shown to extract more K than traditional methods, including some non-exchangeable K, and has been used as an estimate of plant-available K, given its superior correlation to plant uptake[5].

In an attempt to evaluate the various methods for determining the K status of both K-fixing and non-K-fixing soils, we conducted a greenhouse pot experiment in twelve diverse soil materials and at four rates of applied K. Annual ryegrass (*Lolium multiflorum*), which is highly efficient at recovering soil K[6], was grown. Yield and K uptake were measured, and results were compared to laboratory measurements of soil K properties.

Table 1. Soil properties

Code	Soil/Classification	Depth (cm)	XK	TPB-K	TotK	Kfix
			- - -		(mg kg^{-1})	- - -
VSS E	*San Joaquin silt loam*	0-20	79	189	2100	241
	Abruptic Durixeralf	100-120	95	183	3950	632
DH 2	*Guard clay loam*	0-20	194	553	2820	58
	Duric Haplaquoll	40-60	116	234	2810	420
KTR A	*Columbia sandy loam*	0-20	167	770	4500	-26
	Aquic Xerofluvent	40-60	88	300	3940	243
DON A	*Archerdale clay loam*	0-20	269	558	4000	-70
	Pachic Haploxeroll	40-60	159	234	2840	225
RM X	*Redding gravelly loam*	0-20	87	130	830	-45
	Abruptic Durixeralf	40-60	40	66	880	14
DOUG	*Vina fine sandy loam*	0-20	301	395	1430	-186
	Pachic Haploxeroll	40-60	144	155	740	-60

Table 2. Ryegrass K uptake

Pedon Code	Depth (cm)	K rate (mg/kg soil) 0	50	250	1000
		Total uptake (mg/kg soil)			
VSS E	0-20	239	304	590	1069
VSS E	100-120	340	374	587	747
DH 2	0-20	558	633	810	957
DH 2	40-60	153	145	348	689
KTR A	0-20	662	679	907	1042
KTR A	40-60	369	452	648	961
DON A	0-20	681	774	895	959
DON A	40-60	287	333	519	831
RM X	0-20	154	183	435	1043
RM X	40-60	60	126	359	970
DOUG	0-20	324	383	550	791
DOUG	40-60	96	144	325	707

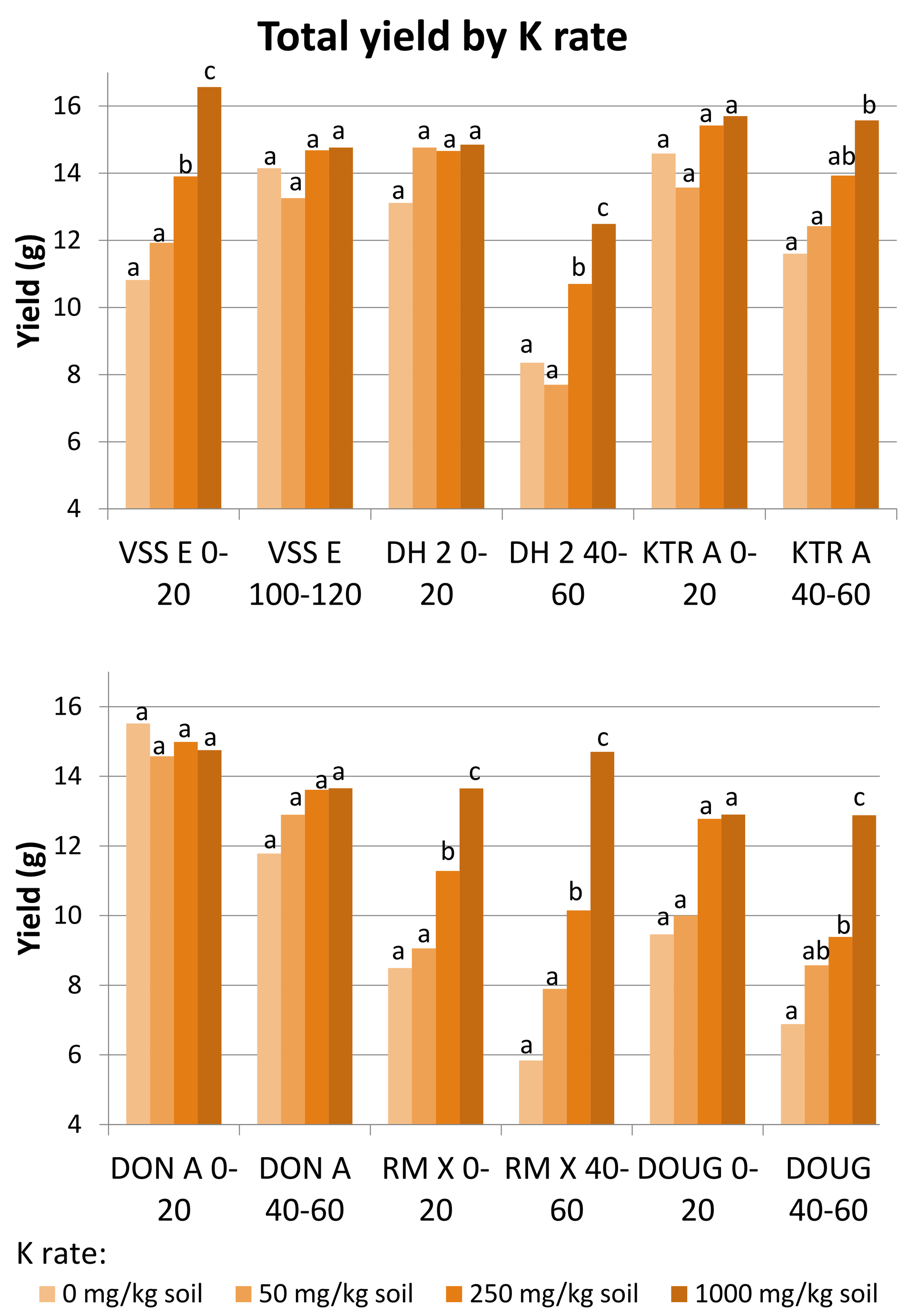

Fig. 1. Total yield by K rate for each of the 12 soil materials used. For each soil, letters indicate significantly different means at the 5% probability level as determined by the Tukey HSD method.

Fig. 2. Visual K deficiency symptoms in annual ryegrass grown in soil VSS E 100-120 with no K added nine weeks after germination. (3rd clipping)

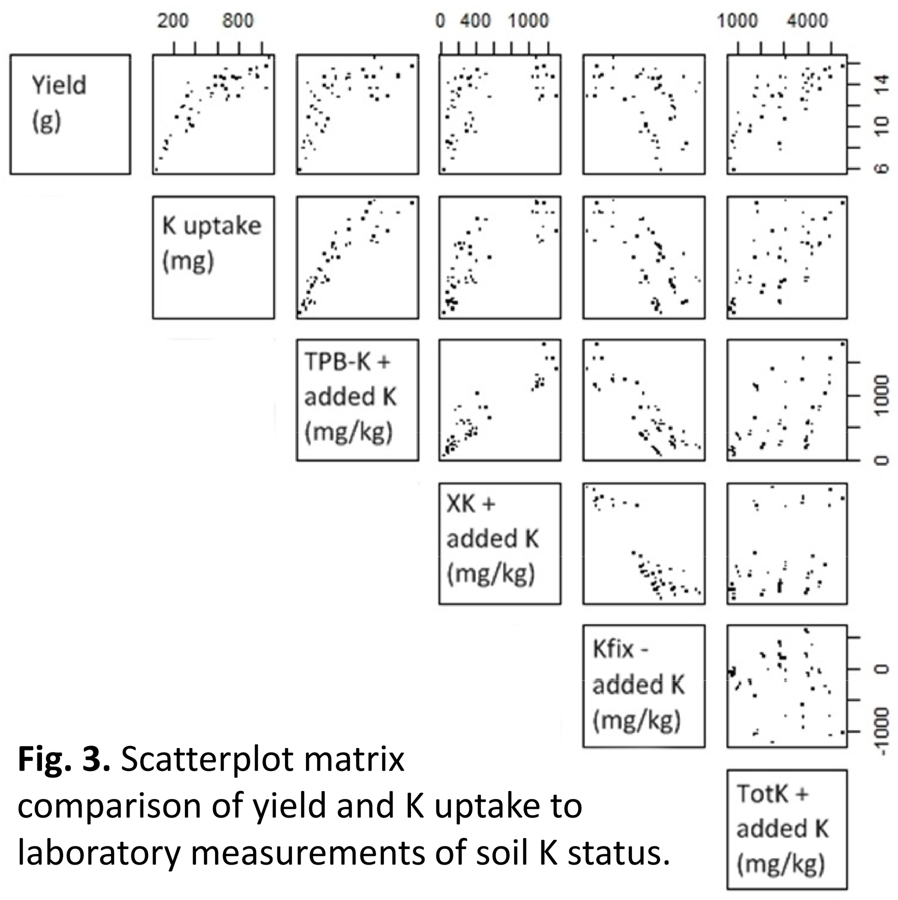

Fig. 3. Scatterplot matrix comparison of yield and K uptake to laboratory measurements of soil K status.

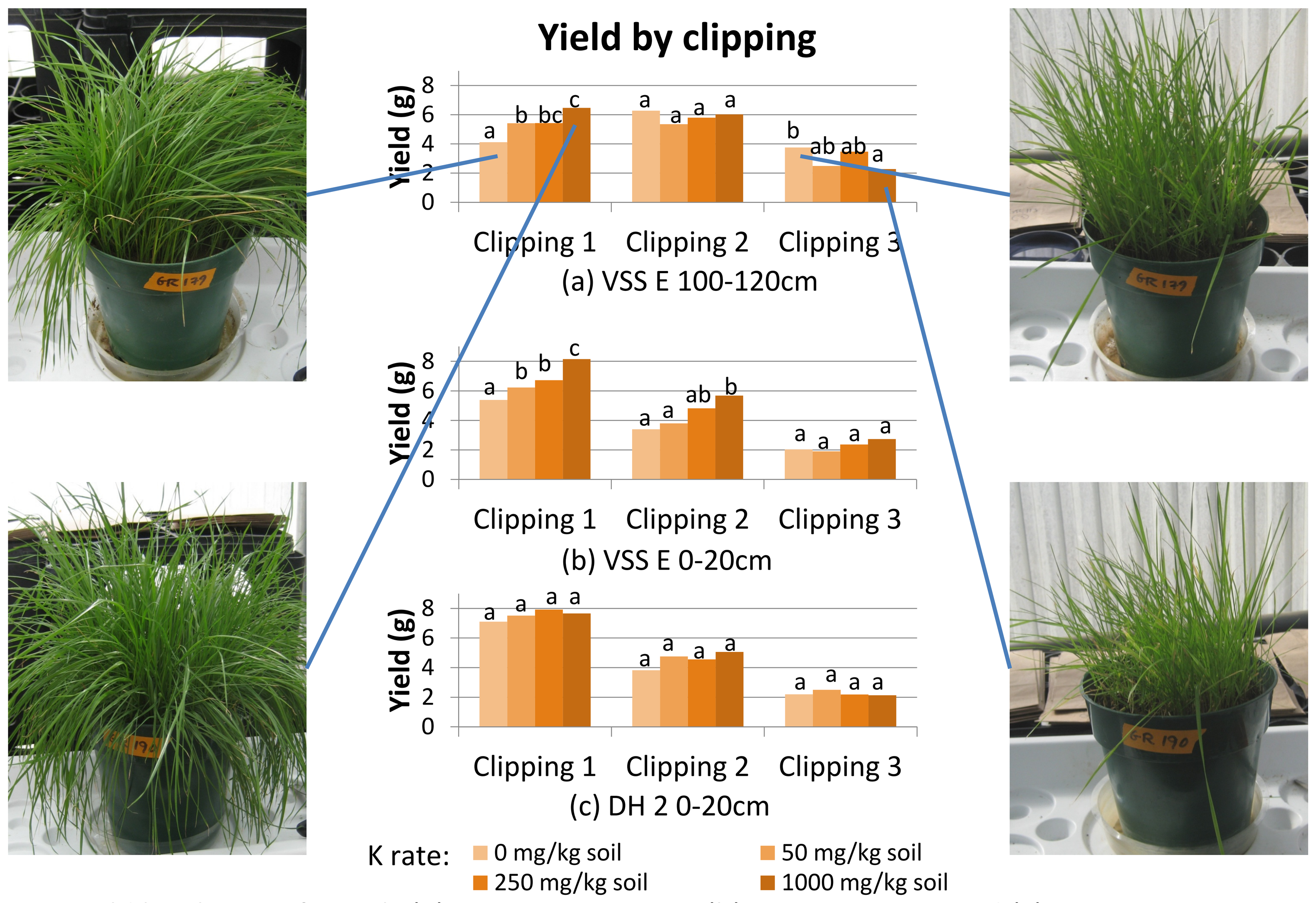

Fig. 4. Yield by clipping for soils (a) VSS E 100-120cm, (b) VSS E 0-20cm, and (c) DH 2 0-20cm. For each clipping, letters indicate significantly different means at the 5% probability level by the Tukey HSD method. Photos show no K and 1000 mg/kg soil K treatments for soil VSS E 100-120 cm at the time of the first and third clippings. The high rate lead to greater initial growth, but this was reversed by the final clipping.

METHODS

Soils

- Soil samples used from six pedons at two depths each from vineyard and almond orchard sites from across the San Joaquin Valley
- Soil properties are shown in Table 1.

Pot experiment

- 1kg soil plus 1kg washed quartz sand mixed with soluble and control release N and P sources, plus K treatments
- K rates of 0, 50, 250, and 1000 mg/kg soil applied as K_2SO_4, with four replicates for each soil/K rate treatment
- Annual ryegrass (*Lolium multiflorum*) seeded at 1.5 g per pot and grown in greenhouse
- Grass harvested by clipping at 1 cm above the soil surface at 3, 6, and 9 weeks after germination
- Oven-dry above ground biomass ("yield") and tissue K measured

Laboratory analysis:

Ammonium acetate-extractable K[7] (XK)

- 2.5-3 g soil saturated and extracted overnight with 1 M NH_4OAc (pH 7) using a mechanical vacuum extractor
- K determined by flame emission spectrometry

K fixation potential[8] (Kfix)

- 3 g soil shaken in 30 mL of 2 mM KCl for 1 h
- Extracted for 30 minutes with 10 mL 4 M NH_4Cl, and centrifuged
- K measured by flame emission spectrometry
- K fixation potential was calculated as the difference between a blank and the measured K solution concentrations

Sodium tetraphenylboron-extractable K[4] (TPB-K)

- 1 g soil extracted for 5 minutes with 3 mL of extracting solution (0.2 M NaTPB + 1.7 M NaCl + 0.01 M EDTA)
- Quenched with 25 mL of 0.5 M NH_4Cl + 0.11 M $CuCl_2$
- Samples heated to boiling for 30-45 minutes to dissolve precipitate
- K measured by flame emission spectrometry

Aqua regia "total K"[9] (TotK)

- 0.500 g ball-milled soil digested with aqua regia for 3 hours at 110°C
- Diluted with 2% nitric acid, filtered, and brought to 250 mL with DI
- K measured by flame emission spectrometry

Tissue K[10]

- Oven-dry grass ground to 40 mesh
- Extracted for 30 minutes with 2% acetic acid
- K measured by flame emission spectrometry

DISCUSSION & SUMMARY

1. Cate-Nelson analysis (carried out in R)[11] established critical values for each soil K determination
   - -XK: 167 mg/kg soil
   - -TPB-K: 419 mg/kg soil
   - -TotK: 1663 mg/kg soil
2. The TPB-K critical value best predicted presence or absence of a significant response to additional K, and TPB-K plus added K best correlated with K uptake (Fig. 3)
3. Soils with initial TPB-K values > 419 mg/kg did not respond to added K, with mixed responses for lower TPB-K soils
4. High K fixation potential of DH 2 40-60cm expressed in significant response to 1000 mg K/kg soil treatment relative to 250 mg K/kg soil, but high K fixing VSS E 100-120 showed no significant response to any level of K application
5. Slowly available fixed K not measured by XK or TPB-K method in VSS E 100-120 may have provided K source for low K treatments, evidenced by increased uptake and yield in final clipping relative to high K treatments (Fig. 4)

REFERENCES

1. Murashkina, M.A., R.J. Southard, and G.S. Pettygrove. 2007. Silt and fine sand fractions dominate K fixation in soils derived from granitic alluvium of the San Joaquin Valley, California. Geoderma 141: 283-293.
2. Rees, G.L., G.S. Pettygrove, and R.J. Southard. 2013. Estimating plant-available potassium in potassium-fixing soils. Comm. in Soil Sci. and Plant Anal. 44:741-748.
3. Scott, A.D., R. R. Hunziker, and J.J. Hanway. 1960. Chemical extraction of potassium from soils and micaceous minerals with solutions containing sodium tetraphenylboron. I. Preliminary experiments. Soil Sci. Soc. of Am. Proc. 24: 46-51.
4. Cox, A.E., B.C. Joern, and C.B. Roth. 1996. Nonexchangeable ammonium and potassium determination in some Midwestern soils using a dmodifies sodium tetrapheylboron method. Soil Sci. Soc. Am. J. 60:114-120.
5. Cox A.E., B.C. Joern, S.M. Brouder, and D. Gao. 1999. Plant-available potassium assessment with a modified sodium tetraphenylboron method. Soil Sci. Soc. Am. J. 63: 902-911.
6. Binet, P., L. el Guessabi, and J. Salette. 1984. The potassium status of soils: significance of the "Italian ryegrass test". Fertilizer Research 5: 393-402.
7. Soil Survey Staff. 2004. Soil Survey Laboratory Methods Manual – Soil Survey Investigations Report No. 42. Version 4.0. USDA-NRCS. Lincoln, NE.
8. Murashkina, M., R. J. Southard, and G. S. Pettygrove. 2007. Potassium fixation in San Joaquin Valley soils derived from granitic and nongranitic alluvium. Soil Sci. Soc. Am. J. 71:125-132.
9. Rajashekhar Rao, B.K., J. Bailey, and R.W. Wingwafi. 2011. Comparison of three digestion methods for total soil potassium estimation in soils of Papua New Guinea derived from varying parent materials. Comm. in Soil Sci. and Plant Anal. 42:1259-1265.
10. Miller, R.O. 1998. Extractable chloride, nitrate, orthophosphate, potassium, and sulfate-sulfur in plant tissue: 2% acetic acid extraction. p. 115-118. *In* Y.P. Kalra (ed.) Handbook of Reference Methods for Plant Analysis. CRC Press, Boca Raton, FL.
11. Mangiafico, S.S. 2013. Cate-Nelson Analysis for Bivariate Data Using R-project. *Journal of Extension* 51: Article #5TOT1. URL http://www.joe.org/joe/2013october/tt1.php

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