TEMPORAL VARIATION IN POTASSIUM CHLORIDE EXTRAC-TABLE ALUMINUM, SODIUM, AND SOIL pH, AND THE EFFECTS ON INTERPRETATION OF SUBSOIL ALUMINUM TOXICITY IN YELLOW EARTHS

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ABSTRACT: Temporal variation in two soil tests ([Al] and the ratio [Al]:[Na] in 1:5 0.005M KCl extract) and pH were evaluated on six occasions during a twelve month study of eleven yellow earths in the Merredin region (31°5, 118°E) of Western Australia. The [Al] and ratio [Al]:[Na] in 1:5 0.005M KCl extracts are useful soil tests capable of distinguishing between productive and non-productive (Al toxic) yellow earths in Western Australia. The aim of the study was to determine the most appropriate time to sample yellow earths, in order to predict accurately which soils contained concentrations of Al in the 15-25 cm layer that were toxic to wheat.

The concentration of Al differed (p<0.05) at three or more sampling times at four of the eleven sites. Temporal variation in [Al] did not affect the identification of Al-toxic and non-toxic yellow earths. The ratio [Al]:[Na] also differed (p<0.05) at three or more sampling times and at six of the eleven sites. The ratio [Al]:[Na] was affected by temporal variation to such an extent, that incorrect diagnosis of potential subsoil Al toxicity could have been made, at four of the eleven sites. Spatial variation was a confounding factor in assessing temporal variation in all soil tests.

If [Al] alone is used to predict Al toxicity in wheat, soil samples could be collected at any time of the year. The most appropriate time to sample soil and use the more accurate soil test, [Al]:[Na], is after summer, but prior to the commencement of winter rainfall patterns and the growing season.

INTRODUCTION

Temporal variation in soil properties is a consequence of the nature of the processes involved in soil development as well as external factors, such as environmental conditions and management practices (1,2,3). Designing and executing pragmatic sampling strategies is necessary when sampling soils if we wish to understand the contribution of temporal variation in a soil test value between sites.

In our previous research, various soil tests were evaluated to identify Al-toxic subsoils (4). Both [Al] and the ratio [Al]:[Na] in 1:5 0.005M KCl extracts were shown to be suitable soil tests capable of distinguishing between soils of low productivity (limited by subsoil Al toxicity) from soils capable of economic wheat yields. The ratio [Al]:[Na] is a more accurate soil test than [Al] alone for predicting grain yield of wheat grown on similar soils in different regions, or when different fertiliser practices have been implemented (4). Prior to the farming community utilising these soil tests, an evaluation of the extent and consequences of temporal variation in [Al] and [Na] extracted by KCl was necessary. Temporal variation in subsoil properties has not been widely documented and is likely to be influenced less by bioloical activity, temperature, and moisture than topsoil properties. Nevertheless, if either of the components of the soil test varied considerably throughout the year, farmers may have to collect soil samples at specific times to avoid non representative soil test values.

The impact of temporal variation on the decision made from the actual measurements needs to be considered. This was because a soil test at any given time (*e.g.* summer) may be statistically different from the same soil test at another sample time (*e.g.* winter), yet the decision made from the soil test (*e.g.* highly Al toxic) may not be affected by such temporal variation in the soil test. The effect of temporal variation on the interpretation of soil test values is particularly important for soils containing concentrations of Al that are marginally toxic.

The aim of the study was to determine the most appropriate time to sample yellow earths in order to predict accurately which soils contained concentrations of Al in the 15-25 cm layer that were toxic to wheat.

MATERIALS AND METHODS

Seasonal variability in two soil tests ([Al] and the ratio [Al]:[Na] in 1:5 0.005M KCl extracts) and soil pH (1:5 0.005M KCl extract) were measured on
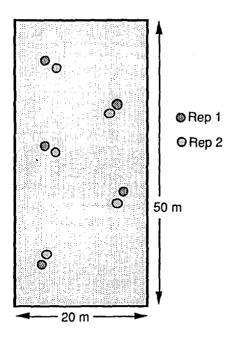
Rep 1

Rep 2

50 m

20 m

FIGURE.1   Representive design of sampling procedure.

six occasions from December 1988 until December 1989 at eleven sites in the
Merredin region. Although soil pH can not distinguish between productive and
non-productive (*i.e.* Al toxic) yellow earths (4), it was measured because it may
provide additional information on possible causes for variation in [Al] during the
study.

Assessment of temporal variation was considered important on soils
designated into three categories: 1) low Al soils (<10 µM in the KCl extract), with
Al toxicity considered unlikely to impose any restriction to wheat yields; 2) high
[Al] soils (>30 µM) that are highly toxic and generally not profitable for growing
wheat; and 3) soils with marginal or intermediate [Al] (10-30 µM).
Soils
The subsoils were collected from the 15-25 cm layer of the yellow earth soils
(Um 5.22,5; Norpa series, 6) in the Merredin region (31°5, 118°E.). The eleven
sites were chosen from previous observation to provide a range of KCl extractable
[Al]. Sites 1 to 4 contained low KCl-extractable [Al] (approximately 10 µM in the

TABLE 1 The geometric mean of [Al] (µM) in a 1:5 0.005M KCl
extract at eleven sites at six sampling times.

Site	Sample date					
	5.12.88	1.3.89	24.5.89	11.7.89	2.10.89	5.12.89
1	8 a*	10 b	10 b	10 b	10 b	10 b
2	11 b	7 a	8 a	8 a	12 b	11 b
3	7 b	10 c	9 c	8 b	8 b	5 a
4	7 b	5 a	5 a	5 a	5 a	6 a
5	32 c	36 c	37 c	34 c	27 b	12 a
6	22 a	30 b	27 b	20 a	30 b	29 b
7	28 d	18 bc	20 c	11 a	18 bc	16 b
8	30 b	22 a	23 a	25 a	25 a	31 b
9	53 d	27 a	53 d	44 c	38 bc	32 b
10	73 a	76 a	77 ab	73 a	73 a	90 b
11	70 a	85 b	67 a	75 ab	70 a	83 b

* Numbers followed by the same letter in the same row are not
significantly (p<0.05) different.

KCl extract). Four sites (sites 5 to 8) had moderate [Al] (20 µM to 30 µM), while
sites 9 to 11 contained high [Al] (>30 µM).

Sampling Procedure

At each site, soils were collected from an area approximately 50 m by 20 m at
six times (5/12/88; 1/3/89; 24/5/89; 11/7/89; 2/10/89, and 5/12/89) during the
twelve month period between December 1988 and December 1989. In order to
decrease spatial variation at each sampling time, each replicate consisted of five
bulked cores (40 mm diameter) from the 15 to 25 cm layer (Fig. 1). The samples
were all air dried at 25°C and stored until analysis.

Laboratory Analysis

Duplicate soil samples were shaken for 16 hours with 0.005M KCl at a soil to
liquid ratio of 1:5, and then centrifuged at 2000 rpm (4). The filtered (<0.45 µM)
extracts were analysed for aluminium colorimetrically using PCV (7), and sodium
by atomic absbrption spectroscopy. Soil pH was measured using a Orion EA 940
research pH meter.

Statistical Analysis

Seasonal variation of the value of KCl-extractable [Al], the ratio [Al]:[NA], and soil pH (measured in the KCl extract) were evaluated by split-plot analysis of variance (8) using MASS (Microprocessor Applied Statistics System, Westat Assoc. Pty. Ltd.). The ratio [Al]:[Na] and [Al] were both log transformed prior to statistical analysis because the soil test values at some sites varied by orders of magnitude. All means of the soil tests [Al] and [Al]:[Na] presented, are therefore, geometric means.

RESULTS AND DISCUSSION

The concentration of Al and the ratio [Al]:[Na] varied ($p<0.05$) temporally at all eleven sites. When [Al] alone was considered, temporal variation did not affect interpretation of the measured values (*i.e.* diagnosis of Al toxicity). However, temporal variation did affect the ability of the ratio [Al]:[Na] to differentiate between soils that contained toxic, or non toxic Al concentrations for wheat growth. Spatial variation was a confounding factor in the assessment of temporal variation in both soil tests.

Aluminium

At sites 1 to 4, [Al] extracted by KCl varied ($p<0.05$) between sampling times (Table 1). The variation between sampling times at these low [Al] sites did not affect the decisions made from the value of the actual soil test. For example, at site 3 the [Al] of 10 μM measured at sample time 2 was twice the [Al] at time 6, but neither concentration would be considered likely to restrict wheat yields on the yellow earths. Hence, the interpretation of the soil test was unaffected by temporal variation because the variation between sample times does not span from non toxic to toxic concentrations.

The four sites that contained intermediate KCl-extractable [Al] varied ($p<0.05$) with time (sites 5 to 8, Table 1). At site 5, [Al] in the first five sampling times were not different ($p<0.05$). On the sixth sampling, [Al] was 12 μM and substantially lower ($p<0.05$) than the [Al] measured on the previous five occasions (approximately 30 μM). Soil pH was 0.2 of a unit higher ($p<0.05$) at time 6 (Table 3) which could explain the decrease in extractable [Al]. There were no obvious reasons for the variation in pH. Presumably spatial variation may have been a contributing factor.

Despite the significant (p<0.05) temporal variation, the interpretation of soil tests (*i.e.* marginal Al toxicity for wheat growth) would not change at these intermediate Al sites. One possible exception occurred at the fourth sample time at site 7, where [Al] was 11 μM which would be considered non limiting (in terms of Al toxicity) to wheat yields. Spatial variation may have contributed to the smaller [Al] at the sample time 4, because the two replicates contained 18 μM and 7 μM [Al], respectively.

The [Al] extracted by KCl from sites 9 to 11 (highly Al toxic soils) also varied (p<0.05) between sampling times (Table 1). The soil test values at sites 10 and 11 remained well above the proposed critical KCl-extractable concentration (>30 μM) at all sampling times, *i.e.* they were highly toxic and this diagnosis was therefore unaffected by temporal variation. The temporal variation at site 9 was such, that [Al] at the second sample time (and to a lesser extent, the final sample time), was much lower (p<0.05) than the [Al] measured on the other four sampling times (times 2 to 5). This variation could change the interpretation of the soil tests. For example, at time 1, [Al] of 53 μM would be assumed to be highly toxic, but the [Al] of 27 μM at the second sample time could be assumed to be moderately toxic. Prior to making an economic decision on the basis of such values, additional samples would have to be assessed. This is because spatial variation could have been responsible for the smaller [Al] at the second sampling time. At this site, at sample time 2, the two replicates contained 16 μM and 45 μM [Al], respectively.

The Ratio [Al]:[Na]

The ratio [Al]:[Na] varied (p<0.05) at three or more sampling times, at six of the eleven sites (Table 2). Interpretation of the soil test values at two of the four low [Al] sites (sites 1 and 3) was unaffected by the temporal variation, with the actual value of [Al]:[Na] at all sample times sufficiently low to conclude Al toxicity would not restrict the yield of wheat on these soils. However, interpretation of soil test values was affected by temporal variation at some sites. For example, at site 2, the ratio [Al]:[Na] at sample times 1, 4, 5, and 6 (Table 2) indicated wheat yields would be limited by Al toxicity. This decision would not be made on the value of the ratio [Al]:[Na] at either the second and third sample times at site 2. Similarly, the ratio [Al]:[Na] on the final sample time at site 4 was ten fold more (p<0.05) than the other five sample times (Table 2)

TABLE 2   The ratio [Al]:[Na] in a 1:5 0.005M KCl extract at eleven sites at six sampling times

Site	Sample date					
	5.12.88	1.3.89	24.5.89	11.7.89	2.10.89	5.12.89
1	0.10 a*	0.13 a	0.14 ab	0.21 b	0.26 b	0.29 b
2	3.87 c	0.89 b	0.44 a	8.02 d	5.28 cd	11.40 d
3	0.15 ab	0.23 b	0.20 b	0.24 b	0.23 b	0.13 a
4	0.37 ab	0.24 a	0.36 ab	0.49 b	0.36 ab	4.67 c
5	0.35 bc	0.20 a	0.43 bc	0.46 c	0.28 b	0.14 a
6	0.19 a	0.27 a	0.20 a	0.23 a	0.56 b	0.54 b
7	5.70 b	2.82 a	3.35 a	11.46 c	13.93 c	11.61 c
8	2.81 b	0.87 a	0.94 a	11.86 d	11.48 d	5.89 c
9	3.13 c	0.78 a	3.37 c	12.08 d	3.65 c	1.73 b
10	15.21 a	75.51 bc	56.89 b	73.11 bc	73.11 bc	89.95 c
11	4.08 b	2.00 a	2.50 a	4.52 b	4.84 b	7.93 c

* Numbers followed by the same letter in the same row are not significantly ($p < 0.05$) different.

The [Al] extracted by KCl at sites 2 and 4 was previously observed not to be affected by temporal variation, therefore the variation in the ratio is due to temporal differences in KCl-extractable [Na]. Sodium extracted by KCl was included in the soil test because it was related to the ionic strength of the soil, and hence provided an indication of toxic Al activity in the soil solution (4). Sodium presumably varies more than extractable Al, because less is adsorbed onto soil surfaces, and hence its concentration would vary more with different soil moisture regimes during the year. A reason for the low KCl-extractable [Na] at sample times 1, 4, 5, and 6 (site 2) and sample time 6 (site 4) was not established. However, from farmer experience, both sites (2 and 4) were very productive yellow earths (J. Thyne and N. Breakall, personal communication).

At sites 5 and 6, the ratio [Al]:[Na] varied ($p < 0.05$) between sample times, but the value always remained low (Table 2). The temporal variation did not affect interpretation that Al toxicity would not restrict wheat yields at sites 5 and 6. This differs from the interpretation made on the basis of [Al] alone at these two sites,

and provides a good indication of the more accurate predictions of potential Al toxicity that can be made from the ratio [Al]:[Na] compared with those made from [Al] alone.

The higher KCl-extractable [Na] at sites 5 and 6 indicates a greater soil solution ionic strength, which would decrease the activity of toxic Al in the soil solution at these sites. Hence, wheat yields on these soils are less affected by subsoil Al toxicity.

The ratio [Al]:[Na] also varied (p<0.05) at site 7 (Table 2), but the observed values were sufficiently high to indicate subsoil Al toxicity would be a major limitation to wheat yields at all sample times. This is despite considerably lower KCl-extractable [Al] at site 7, compared with the [Al] at sites 5 and 6 (Table 1), and is because KCl-extractable [Na] was very low at site 7. The low KCl-extractable [Na] at site 7 indicates a low soil solution ionic strength, and therefore, high activity of Al. This observation reinforces the advantages of the ratio [Al]:[Na] in distinguishing between productive and non productive yellow earths.

The ratio [Al]:[Na] varied considerably (p<0.05) at site 8. At sample times 2 and 3, the soil test values indicated no restriction in wheat growth by Al toxicity, but at the other four sample times, the values suggested severe subsoil Al toxicity. The [Al] extracted by KCl did not vary with time, hence the variation in the ratio at this site was due to temporal differences in KCl-extractable [Na] (as observed at sites 2 and 4). Spatial variation was not considered to be a contributing factor, because the replicates had very similar [Na] (data not shown).

The ratio [Al]: [Na] at the three sites with severe subsoil Al toxicity (sites 9 to 11) also varied (p<0.05) between sample times, however the observed values were sufficiently high at all sample times to indicate wheat yields would be restricted by Al toxicity if grown at sites 10 and 11. At site 9, the ratio [Al]:[Na] at sample time 2 was considerably lower (p<0.05) than the values estimated on the other five occasions (Table 3). Consequently, the interpretation at this site changes from highly Al toxic subsoils, to only slightly Al toxic. Spatial variation in the [Al] was previously suggested as a possible cause of the lower value at sample time 2. In addition to spatial variation in [Al], there were strong indications that [Na] extracted by KCl at site 9 at sample time 2 was also influenced by spatial variation. For instance, the two subsamples contained [Al] of 16 μM and 45 μM, and [Na] of 83 μM and 14 μM, respectively. Clearly, both the lower [Al] and higher [Na] of the first subsample contributed to the lower value of the ratio

TABLE 3   Soil pH measured in 1:5 0.005M KCl extract at eleven sites at six sampling times.

Site	Sample date					
	5.12.88	1.3.89	24.5.89	11.7.89	2.10.89	5.12.89
1	4.30 a*	4.28 a	4.32 ab	4.28 a	4.30 a	4.35 b
2	4.30 a	4.44 c	4.43 c	4.41 c	4.34 b	4.36 b
3	4.41 ab	4.43 b	4.37 a	4.41 ab	4.42 b	4.57 c
4	4.44 a	4.51 b	4.56 c	4.56 c	4.54 bc	4.54 bc
5	4.02 a	4.00 a	4.01 a	4.02 a	4.07 a	4.24 b
6	4.10 b	4.05 a	4.07 ab	4.10 b	4.05 a	4.08 ab
7	4.14 a	4.25 b	4.21 b	4.34 d	4.26 b	4.29 b
8	4.19 a	4.25 b	4.22 ab	4.21 ab	4.24 b	4.21 ab
9	4.00 a	4.15 d	4.02 a	4.05 b	4.09 c	4.15 d
10	4.02 ab	4.01 ab	3.99 a	4.00 a	4.03 ab	4.04 b
11	3.99 a	4.01 ab	4.03 b	4.00 ab	4.03 b	4.00 ab

* Numbers followed by the same letter in the same row are not significantly ($p<0.05$) different

[Al]:[Na] at site 9 on sample time 2. As previously suggested, perhaps more comprehensive sampling should be undertaken prior to making a final management decision at such a site.

Soil pH

Soil pH measured in the 0.005M KCl extract also varied ($p<0.05$) during the twelve month study (Table 3). The difference between the maximum and minimum pH at a given site varied from 0.04 (site 11) to 0.20 (Site 7) of a pH unit. The fact that soil pH was less variable than the soil tests [Al] and [Al]:[Na] is attributed to the logarithmic scale of measurement used for pH.

There was no indication of a seasonal pattern to the variation observed in soil pH, however at the final sample time (December 1989), seven of the eleven sites had higher ($p<0.05$) pH values than the first sample time in December 1988. There was no difference in pH between the first and last sampling times at the other four sites (Table 3)

Spatial variation was also a confounding factor in the assessment of temporal variation in soil pH. There were significant (p<0.05) differences in soil pH of the replicates at a number of sites within the same sample time (data not shown).

CONCLUSIONS

Temporal variation in [Al] was observed at all sites, however the variability was not sufficient to significantly alter interpretation of soil test values at eight of the eleven sites. Spatial variation was considered to be a confounding factor in the identification of temporal variation in this study. Providing soil sampling strategies are used to decrease the effect of spatial variation, farmers and researchers should be able to predict potential Al toxicity to wheat grown on yellow earths from soil samples collected at any time throughout the year.

The ratio [Al]:[Na] is a more accurate soil test than [Al] alone for predicting grain yield of wheat grown on similar soils in different regions, or when different fertiliser practices have been implemented (4). This is because the [Na] extracted by the KCl is related to the ionic strength of the soil, and hence, provides an indication of toxic Al activity in the soil solution. Despite the greater predictive ability of [Al]:[Na], temporal variation has a greater affect on the ratio [Al]:[Na] than [Al] alone. Hence, soil samples must be collected at times when KCl-extractable [Na] is similar to the concentration found during most of the growing season.

When all sites were considered, the most appropriate time to sample soil and use the soil test [Al]:[Na] to determine potential wheat yields would be in late summer or early autumn (*i.e.* either the second or third sample times). Winter rainfall patterns rarely commence before late May in the Merredin region, and therefore, changes in soil chemical properties after the commencement of such would be minimal. There was only one instance at sample times 2 and 3, *i.e.* one of the 22 site/times (an error of <5 %) when the actual value of the soil test could be interpretted incorrectly (site 9, time 2), and spatial variation was considered the major factor for that extraneous estimation of [Al]:[Na].

Soil pH is relatively unaffected by temporal variation, however pH is unable to provide information on subsoil Al toxicity on the yellow earths, therefore it is of little value as a routine soil test.

ACKNOWLEDGEMENTS

REFERENCES:

1. Haines, S. G. and Cleveland, G. 1981. Seasonal variation in properties of five forest soils in southwest Georgia. Soil Sci. Soc. Am. J. 45:139-143.

2. Peterson, D. L. and Rolfe, G. L. 1982. Seasonal variation in nutrients of floodplain and upland forest soils in central Illinois. Soil Sci. Soc. Am. J. 46:1310-15.

3. Peterson, D. L. and Hammer, R. D. 1986. Soil nutrient flux: a component of nutrient cycling in temperate forest ecosystems. For. Sci. 32:318-324.

4. Carr, S. J., Ritchie, G. S. P., and Porter, W. M. 1991. A soil test for subsoil aluminium toxicity in the yellow earth soils of Western Australia. Aust. J. Agric. Res. 42:875-892.

5. Northcote, K. H. 1979. A factual key for the recognition of Australian soils. Rellim Technical Publications. Adelaide, S. A.

6. Bettenay, E. and Hingston, F. J. 1961. The soils and land use of the Merredin area, Western Australia. CSIRO Australian Division of Soils, Soils Land Use. Seriel No .41.

7. Dougan, W. K. and Wilson, A. L. 1974. The absorptiometric determination of aluminium in water. A comparison of some chromogenic reagents and the development of an improved method. Analyst. 99:413- 430

8. Snedecor, G. W. and Cochran, W. G. 1980. Statistical Methods. 7th Edition. The Iowa State University Press, Ames, IA.