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Research highlights:

- A glasshouse experiment measured the bioavailability of K in zeolite N, made by caustic reaction with kaolin.).
- The elemental compositions of plants supplied with K as K-zeolite N and soluble K fertiliser were similar except for Si being significantly more concentrated in the plants supplied with K-zeolite N.
- For non-leached pots the agronomic effectiveness of K-zeolite N as a potassic fertiliser was superior to. KCl .This may reflect the high Si concentration in plants grown with K-zeolite N combating fungal disease.

1 **Use of a zeolite synthesized from alkali treated kaolin as a K fertiliser:**
2 **Glasshouse experiments on leaching and uptake of K by wheat plants in sandy**
3 **soil**

4
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12
13 **Abstract**

14
15 Zeolite N, a zeolite referred to in earlier publications as MesoLite, is made by caustic reaction
16 of kaolin at temperatures between 80 °C and 95 °C. This material has a very high cation
17 exchange capacity (CEC \approx 500 meq/100g). Soil column leaching experiments have shown that
18 K-zeolite N additions greatly reduce leaching of NH₄⁺ fertilisers but the agronomic
19 effectiveness of the retained K⁺ and NH₄⁺ is unknown.

20 To measure the bioavailability of K in this zeolite, wheat was grown in a glasshouse with K-
21 zeolite N as the K fertiliser in highly-leached and non-leached pots for four weeks and
22 compared with a soluble K fertiliser (KCl).

23 The plants grown in non-leached pots and fertilised with K-zeolite N were slightly larger than
24 those grown with KCl. The elemental compositions in the plants were similar except for Si
25 being significantly more concentrated in the plants supplied with K-zeolite N. Thus K-zeolite
26 N may be an effective K-fertiliser.

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27 Plants grown in highly-leached pots were significantly smaller than those grown in non-
28 leached pots. Plants grown in highly-leached pots were severely K deficient as half of the K
29 from both KCl and K-zeolite N was leached from the pots within three days.

30

31 **Keywords:** Zeolite N; Potassium fertiliser; Wheat; Glasshouse experiment; Nutrient
32 leaching

33

34 **1. Introduction**

35 Very sandy soils may have inadequate water and nutrient retention for supporting plant
36 growth. To improve these soils for agriculture, horticulture or turf grass, zeolite is sometimes
37 applied as a soil amendment (Ferguson et al., 1986; Nus and Brauen, 1991; Wehtje et al.,
38 2003; Malekian et al., 2011). Zeolite increases the CEC of soil (Suwardi et al., 1994) and
39 reduces leaching of cationic plant nutrients (Huang and Petrovic, 1994; Malekian et al., 2011).
40 Zeolite may also improve the physical properties of soils including water retention and
41 resistance to water repellence (Petrovic, 1990; Xiubin and Zhanbin, 2001). Natural zeolite has
42 been used as a slow release fertiliser providing either natural or added elements (Williams and
43 Nelson, 1997; Carlino et al., 1998; Perrin et al., 1998a; b). However, much of the agronomic
44 research has omitted the characterisation of zeolitic materials in relation to this application
45 (Ming and Allen, 2001).

46 A synthetic zeolite referred to by the trade name MesoLite was developed to have a high
47 ammonium (NH_4^+) exchange capacity for wastewater treatment (Thornton et al., 2007a, b)
48 with an effective cation exchange capacity (CEC) of approximately 500 meq/100g measured
49 by the NH_4Cl -KCl exchange method (Mackinnon et al., 2003). Recent work by Mackinnon et
50 al. (2010) has shown that this synthetic material is zeolite N of known structure (Christensen
51 and Fjellvag, 1997).

52 In our previous work (Zwingmann et al., 2009) we measured the retention of NH_4^+ by
53 MesoLite, or zeolite N, loaded with K^+ using a soil column leaching procedure. We also
54 showed that NH_4^+ was gradually released from NH_4^+ -exchanged zeolite N on leaching. This
55 result suggested the potential of this material for use as a slow release nitrogen fertilizer and,
56 by analogy, the potassic form of zeolite N may also release K^+ to plants.
57 This property will be particularly valuable for very sandy soils where leaching of soluble
58 fertiliser is wasteful and an environmental hazard (Carpenter et al., 1998; Ball and Sinclair
59 Knight Merz Pty Limited, 2001). In this paper we present the results of a glasshouse
60 experiment to measure the availability of K in potassic zeolite N to plants grown on a very
61 sandy soil under high and nil leaching conditions. We relate this agronomic information to the
62 characteristics of the as-produced potassic form of zeolite N.

63

64 **2. Materials and Methods**

65

66 **2.1. Materials**

67 Bassendean sand from Kwinana, 50 km south from Perth (Western Australia) was used for the
68 glasshouse experiments and consists mostly of quartz. This soil is classified in the Australian
69 Soil Classification as a podosol (Isbell, 2002). The pH (H_2O) of the soil is 5.9 and electrical
70 conductivity (EC) 20 $\mu\text{S}/\text{cm}$ (soil: DI water = 1:5). It contains 0.28 % C and 0.05 % N, and
71 the total K content is below the detection limit of XRF analysis (<0.01 %).

72 Zeolite N, or MesoLite, was manufactured by NanoChem Holdings Pty. Ltd. Queensland,
73 Australia by caustic reaction with kaolin at a temperature between 80 °C and 95 °C
74 (Mackinnon, 1998; Mackinnon et al., 2010). For the present study, potassic zeolite N (K-
75 MesoLite in which the exchangeable cation is K^+) was used as a K fertiliser. A detailed
76 description of potassic zeolite N (K-zeolite N) which has a CEC ~500 meq/100g has been
77 published by Mackinnon et al. (2003), Zwingmann et al. (2009) and Mackinnon et al. (2010).

78 Experimental CEC values for zeolite N were determined for equilibrium exchange of
79 ammonium ion in a 1M NH₄Cl solution (Mackinnon et al., 2010) calibrated against the Cheto
80 montmorillonite consistent with the determination by Jaynes and Bingham (1986). The unit
81 cell formula for zeolite N is K₁₂Al₁₀Si₁₀O₄₀Cl₂·8H₂O (Christensen and Fjellvag, 1997;
82 Mackinnon et al., 2010). The measured CEC value for zeolite N used in these experiments is
83 502 meq/100g. The method used to produce this zeolite N is equivalent to reactions 1 and 2
84 described in Mackinnon et al. (2010).

85 The pH (H₂O) of K-zeolite N was 11 and EC was 4.2 mS/cm (solid: DI water = 1:5). The pH
86 (H₂O) and EC for soil with K-zeolite N applied at the highest application rate (89 mg K/kg
87 soil) remained close to the values for Bassendean sand, being pH 6.3 and EC 23 µS/cm,
88 respectively. Chemical analyses of Bassendean sand and K-zeolite N are shown in Table 1.

89 **2.2. Procedure for the glasshouse experiment**

90 Soil (6-10 cm) was air-dried and sieved to less than 4 mm. Basal nutrients and various
91 amounts, from 2.8 up to 89 mg/kg soil, of K-fertiliser K-zeolite N and KCl as a reference
92 soluble fertiliser (Table 2) were added to 1.2 kg soil, mixed and placed in 13 cm diameter
93 black plastic pots. All the nutrients were added once only before sowing except for N, which
94 was added first before sowing and the same amount again two weeks after sowing. One group
95 of plants was grown in leached pots and another group grown in non-leached pots. For each
96 condition, the experiments were in triplicate. These pots were watered with de-ionised water
97 (DI water) to the water hold by the soil at the beginning of experiments the day before
98 sowing. Ten pre-germinated wheat (*Triticum aestivum L.*) seeds were sown per pot at 1cm
99 depth and the pots were then placed in a glasshouse. The plants in non-leached pots were
100 watered every day with DI water to maintain the soil at 95 % of the water hold by the soil at
101 the beginning of experiments The plants in the highly-leached pots were watered daily with
102 DI water and with an amount corresponding to 5 mm excess that leached from the soil. This

103 watering represents a very high-leaching situation. The leachates from the highly-leached pots
104 were collected, weighed, acidified with 1 mol/L HCl and kept in a cool room at 5 °C prior to
105 K analysis. The pots were randomized every day. At the two leaf stage, plants were thinned to
106 five seedlings per pot by selecting the five most uniform plants. Three weeks post-emergence,
107 plants became affected by fungus and all the pots were treated with K-free fungicide. Twenty-
108 five days post-emergence, the plants were cut at 5 mm from the soil and dried at 70 °C for
109 weighing and elemental analysis.

110 **2.3. Methods for material characterisation and leachate analysis**

111 Elemental analysis was carried out by X-ray Fluorescence Spectrometry (Philips, PW 1730)
112 on fused bead samples for Bassendean sand and K-zeolite N and on pressed pellets for plant
113 material. Finely ground plant samples of approximately 0.3 g with 0.13 mL PVA solution as
114 binder were mixed well and pressed on to a boric acid base at 350 bar using a Sietronics
115 Autopress. Some plant samples with extremely low yield were diluted with cellulose to make
116 0.3 g and 0.13 mL PVA solution added as binder. C and N contents of the dried plant material
117 were determined with a LECO CHN-1000 analyser. Due to the small amounts of plant
118 material, XRF and C/N analysis was carried out on combined plant material from the
119 triplicate treatments. Concentrations of K⁺ in the leachates were determined by atomic
120 absorption spectrometry (Perkin Elmer, AAanalyt 300).

121

122 **3. Results**

123 **3.1. Leaching of K from highly-leached pots**

124 Applied K leached quickly from the highly-leached pots for both K-zeolite N and KCl.
125 Figures 1a, 1b show the amount of K leached from the soil on a daily basis and Figures 1c, 1d
126 show the cumulative percentages of K leached over time. Higher amounts of K leached during
127 the first days (Figures 1a, 1b) and half of the total K applied had leached from the pots
128 between one day (blank and low K pots) and 3 days (K-zeolite N: 89 mg K/kg soil) (Figures

129 1c, 1d). Leaching was slower for K-zeolite N and also less K had been leached (10-30 % for
130 K-zeolite N, 5-20 % for KCl) after 28 days.

131

132 **3.2. Yield**

133 The weight of the plants grown in non-leached pots increased with K fertiliser application rate.

134 The plants grown with K-Zeolite N at higher application rates were heavier than those

135 supplied with equivalent amounts of soluble fertiliser (Figure 2a). For comparison, the

136 weights of plants grown in highly-leached pots are plotted in Figure 2b. For the highly-

137 leached pots, the x-axis is “K applied - K leached (mg/kg soil)” at the time of harvest due to

138 severe leaching of K (see Figures 5c, 5d). The plants in highly-leached pots were less than

139 one eighth the weight of plants grown in non-leached pots and relatively larger yields were

140 obtained for K-zeolite N compared to KCl where very little K was retained in the soil.

141

142 **3.3. K and other elements in plants**

143 The concentration of K in the plants grown in non-leached pots increased with the application

144 rate and the amounts of K taken by plants are similar for both KCl and K-zeolite N. The

145 concentrations of K in the plants grown in highly-leached pots are shown as a function of “K

146 applied - K leached” (Figure 3a). The concentrations of K in the plants grown with K-zeolite

147 N in highly-leached pots were much higher than for the same “K applied - K leached” for

148 non-leached pots. These higher concentrations of K are probably due to the low weight of the

149 plants in the highly-leached pots due to plant growth being reduced due to multiple nutrient

150 deficiencies. Figure 3b (and enlargement in Figure 3c) shows that the internal efficiency of K

151 for plants supplied with K-zeolite N in non-leached pots was higher than for plants supplied

152 with KCl when yields were greater than 1 g/pot.

153 The concentrations of other plant nutrient elements for plants grown in leached and non-

154 leached pots are shown as a function of yield (weight of the plant) in Figure 4. For all

155 elements except chlorine and silicon, the concentration decreased with increased plant weight
156 due to increased plant growth reflecting the removal or reduction of K-limited plant growth
157 conditions.

158 The concentration of Si in the plants grown with KCl (control) decreased with increasing
159 yield while it increased for the plants fertilised with K-zeolite N which evidently acts as a Si-
160 fertiliser.

161 According to the deficiency criteria of Reuter and Robinson (1997), concentrations of Na, S,
162 Cu, Mn and Zn were sufficient and the concentration of Cl is low enough not to cause toxicity.
163 However, larger plants supported by high K application rates and plants in highly-leached
164 pots may have experienced marginal P, N, Mg and Ca deficiencies.

165

166 **3.4. K mass balance**

167 Figure 5 shows the mass balance of K for highly-leached and non-leached pots: initial total K
168 (applied K plus blank K) is either absorbed by plants, remains in the soil or is leached from
169 the soil in the case of highly-leached pots. For the non-leached pots (Figure 5a, 5b), the
170 amounts of K taken up by plants from K-zeolite N were higher than for KCl for the higher K
171 application rates. Approximately 40-50 % or more of the applied K was used by plants
172 (Figure 5b). For highly-leached pots, most of the initial K was leached from the pots.

173 Therefore very little K was left for plants, in particular if K was applied as KCl when more
174 than 85 % was leached (Figure 5c, 5d). Leaching of K was slightly less when K was applied
175 as K-zeolite N with more of the retained K being in the soil rather than in the plants at higher
176 application rates.

177

178 **3. Discussion**

179 These results indicate that much of the K in zeolite N was released into soil solution and was
180 available for plants. For non-leached pots, the plants grown with K-zeolite N were larger than

181 the plants provided with KCl, and the internal efficiency of K was higher for plants grown
182 with K-zeolite N.

183 Plants grown in highly-leached pots supplied with KCl grew poorly with no relationship
184 existing between yield and KCl application rate due to severe leaching of most K and basal
185 nutrients at the early stage of plant growth. More than 85 % of K was leached and
186 consequently, only a few % of initially applied K was available for the plants. Plants grown
187 with K-zeolite N in highly-leached pots were slightly larger than for KCl but more than 75 %
188 of K from K-zeolite N was leached from the pots leaving less than 25 % of applied K
189 available for the plants. The source of K found in the leachate from the pots with no K
190 fertiliser (Figure 5c) is unknown. It could have originated from the seeds, water or more likely
191 from the soil, where the total K was below the detection limit of XRF methods, but K may be
192 detected by AAS analysis in the leachates due to higher sensitivity of AAS technique.

193 These data show that K in K-zeolite N is susceptible to leaching despite being present in a
194 non-soluble form. Presumably, K was released primarily by cation exchange in particular with
195 NH_4^+ , Ca^{2+} , and Mg^{2+} which are major constituents of the basal nutrient solutions
196 (Zwingmann et al. 2009). Thus K-zeolite N cannot be recommended for use on very sandy
197 soils which are very highly-leached and which receive large additions of cation rich fertilisers.
198 However, K-zeolite N is suitable for soils that do not experience severe leaching – the
199 common situation for horticulture.

200 K-zeolite N increased the Si concentration in wheat for which Si is an essential nutrient.
201 Several studies have shown that silicon enhances resistance of plant to both abiotic and biotic
202 stresses, including fungal diseases (e.g. Ma et al., 2001; Rodrigues et al., 2002; Ma, 2004; Ma
203 and Yamaji, 2006; Bacchus, 2010). In this experiment, plants were affected by a fungal
204 disease after the third week. Plants fertilised with KCl contained less Si and were more
205 affected than those fertilised with K-zeolite N.

206 This experiment showed the K availability and influence of K-zeolite N on plants during the
207 early growth stage. The longer term influence of K-zeolite N use as a fertiliser on wheat and
208 other plants will be the subject of further investigation.

209 **4. Conclusions**

210 This glasshouse experiment has shown that K from K-zeolite N is available for plants and is a
211 superior source of K under non-leaching conditions. K from K-zeolite N is released by cation
212 exchange particularly with NH_4^+ , Ca^{2+} , and Mg^{2+} present in the basal nutrient solution. For
213 highly-leached soilpots, most K was rapidly leached from the pots with more than 85 % of K
214 from KCl and 75 % of K from K-zeolite N being leached. For non-leached pots, the
215 agronomic effectiveness of K-zeolite N as a potassic fertiliser was superior to that of a soluble
216 KCl fertiliser. The internal efficiency of K use by plants supplied with K-zeolite N was
217 higher than that for plants supplied with KCl. The higher yield of plants supplied with K-
218 zeolite N may, to some extent, reflect the higher Si concentration in plants grown with K-
219 zeolite N because the elevated plant Si helped to combat fungal disease.

220

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228

229 **References**

- 230 Bacchus, G.L., 2010. An Evaluation of the influence of biodynamic practices including foliar-
231 applied silica spray on nutrient quality of organic and conventionally fertilised lettuce
232 (*Lactuca Sativa L.*) Journal of Organic Systems 5, 4-13.
- 233 Ball and Sinclair Knight Merz Pty Limited, 2001. Inland Waters. Australia State of the
234 Environment Report 2001 (Theme Report) CSIRO Publishing, Collingwood, Australia.
- 235 Carlino, J., Williams, K. A, Allen, E. R., 1998. Evaluation of zeolite-based soilless root media
236 for potted chrysanthemum production. HortTechnology 8, 373-378.
- 237 Carpenter, S.R., Caraco, N.F., Correll, D.L., Howarth, R.W., Sharpley, A.N., Smith, V.H.,
238 1998. Nonpoint pollution of surface waters with phosphorous and nitrogen. Ecological
239 Application 8, 559-568.
- 240 Christensen, A. N., Fjellvag, H., 1997. Crystal structure determination of zeolite N from
241 synchrotron X-ray powder diffraction data. Acta Chemica Scandinavica 51, 969-973.
- 242 Ferguson, G.A., Pepper, I.L. Kneebone, W.R., 1986. Growth of creeping bentgrass on a new
243 medium for turfgrass growth; Clinoptilolite zeolite-amended sand. Agronomy Journal 78,
244 1095-1098.
- 245 Huang, Z. T. and Petrovic, A. M., 1994. Soil Process and Chemical Transport - Clinoptilolite
246 zeolite influence on Nitrate leaching and Nitrogen use efficiency in simulated sand based golf
247 greens. Journal of Environmental Quality 23, 1190-1194.
- 248 Isbell, R.F., 2002. The Australian soil classification. Australian soil and land survey handbook
249 v.4., CSIRO Publishing, Collingwood, Australia.
- 250 Jaynes, W.F.; Bingham, J.M., 1986. Multiple cation-exchange capacity measurements on
251 standard clays using a commercial mechanical extractor. Clays and Clay Minerals 34, 93–98.
- 252 Ma, J.F., Miyake, Y., Takashashi, E., 2001. Silicon as a beneficial element for crop plants, In
253 in: Datnoff, L.E., Snyder, G.H. Korndörfer, G.H. (Eds.), Silicon in Agriculture. Elsevier,
254 Amsterdam. pp. 17-39.
- 255 Ma, J.F., 2004. Role of silicon in enhancing the resistance of plants to biotic and abiotic

- 256 stresses. *Soil Science & Plant Nutrition*. 50,11-18.
- 257 Ma, J.F., Yamaji, N. 2006. Silicon uptake and accumulation in higher plants. *Trends in Plant*
258 *Science*. 11, 392-397.
- 259 Mackinnon, I.D.R., 1998. Value-added products from modified kaolins: New chemical routes
260 to new markets. *Industrial Minerals*1998, 138-146.
- 261 Mackinnon, I.D.R., Barr, K., Miller, E., Hunter, S., Pinel, T., 2003. Nutrient removal from
262 wastewaters using high performance materials. *Water Science and Technology*, 47, 11, 101-
263 107.
- 264 Mackinnon, I.D.R., Miller, E., Stolz, W. 2010. Low temperature synthesis of zeolite N from
265 kaolinites and montmorillonites. *Applied Clay Science* 48, 622-630.
- 266 Malekian, R.,Abedi-Koupai, J., Saeid Eslamian, S., 2011. Influences of clinoptilolite and
267 surfactant-modified clinoptilolite zeolite on nitrate leaching and plant growth. *Journal of*
268 *Hazardous Materials*, 185, 970-976.
- 269 Ming, D.W., Allen, E.R., 2001. Use of Natural Zeolites in Agronomy, Horticulture, and
270 Environmental Soil Remediation. In: Bish, D., Ming, D.W., (Eds.), *Natural Zeolites:*
271 *Occurrence, Properties, Applications*. *Reviews in Mineralogy & Geochemistry*, Mineralogical
272 Society of America, Washington, DC, 45, pp. 619-654.
- 273 Nus, J.L. Brauen, S.E., 1991. Clinoptilolite zeolite as an amendment for the establishment of
274 creeping bentgrass on sand media. *HortScience* 26, 117-119.
- 275 Perrin, T. S., Boettinger, J. L., Drost, D. T., Norton, J. M., 1998a. Decreasing Nitrogen
276 leaching from sandy soil with Ammonium-loaded clinoptilolite. *Journal of Environmental*
277 *Quality* 27, 656-663.
- 278 Perrin, T. S., Drost, D. T., Boettinger, J. L., Norton, J. M., 1998b. Ammonium-loaded
279 clinoptilolite: A slow-release Nitrogen fertilizer for sweet corn. *Journal of Plant Nutrition* 21,
280 515-530.

- 281 Petrovic, M. A., 1990. The potential of natural zeolite as a soil amendment. *Golf Course*
282 *Management* (November issue) 92-94.
- 283 Reuter, D.J., Robinson, J.B. (Eds.) 1997. *Plant analysis: an interpretation manual*. 2nd edition.
284 CSIRO Publishing. Collingwood, Australia.
- 285 Rodrigues, F.Á., Vale, F.X.R, Datnoff L.E., Prabhu, A.S., Korndörfer G.H. 2002. Effect of
286 rice growth stages and silicon on Sheath Blight development. *Phytopathology* 93, 256-261.
- 287 Suwardi, Goto, I, Ninaki, M., 1994. The quality of natural zeolites from Japan and Indonesia
288 and their application effects for soil amendment. *J Agricultural Science Tokyo Nogyo*
289 *Daigaku*. 39, 133-148.
- 290 Thornton, A., Pearce, P., Parsons, S.A., 2007a. Ammonium removal from digested sludge
291 liquors using ion exchange. *Water Research* 41, 433–439.
- 292 Thornton, A., Pearce, P., Parsons, S.A., 2007b. Ammonium removal from solution using ion
293 exchange on to MesoLite, an equilibrium study. *Journal of Hazardous Materials* 147, 883-889.
- 294 Wehtje, G.R., Shaw, J.N., Walker, R. H., Williams, W., 2003. Using inorganic soil
295 amendments to improve a native soil. *Golf Course Management* (November issue) 95-99.
- 296 Williams, K. A., Nelson, P. V., 1997. Using precharged zeolite as a source of potassium and
297 phosphate in a soilless container medium during potted Chrysanthemum production. *Journal*
298 *of the American Society for Horticultural Science* 122, 703-708.
- 299 Xiubin, H., Zhanbin, H., 2001. Zeolite application for enhancing water infiltration and
300 retention in loess soil. *Resources, Conservation and Recycling* 34, 45-52.
- 301 Zwingmann, N., Singh, B., Mackinnon, I.D.R., Gilkes, R. J., 2009. Zeolite from alkali
302 modified kaolin increases NH_4^+ retention by soil: column experiments. *Applied Clay Science*
303 46, 7-12.
- 304

Table 1

[Click here to download Table: glasshouse paper_Table 1.docx](#)**Table 1: Chemical composition of the soil and K-zeolite N**

		Bassendean sand	K-zeolite N
Al ₂ O ₃	(%)	0.10	27.12
SiO ₂	(%)	96.37	32.68
TiO ₂	(%)	0.08	0.72
Fe ₂ O ₃	(%)	0.02	0.78
MnO	(%)	b.d.	b.d.
CaO	(%)	b.d.	0.23
K ₂ O	(%)	b.d.	26.05
MgO	(%)	b.d.	0.22
Na ₂ O	(%)	b.d.	0.01
P ₂ O ₅	(%)	b.d.	b.d.
SO ₃	(%)	b.d.	b.d.
V	(ppm)	b.d.	29
Cr	(ppm)	b.d.	b.d.
Ni	(ppm)	14	b.d.
Cu	(ppm)	18	34
Zn	(ppm)	b.d.	b.d.
Rb	(ppm)	4	12
Sr	(ppm)	b.d.	19
Ba	(ppm)	b.d.	88
Zr	(ppm)	35	154
Co	(ppm)	1	2
LOI		3.65	12.25
N	(%)	0.06	0.08
C	(%)	0.28	0.33

b.d.: below detection limit

Table 2

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Table 2: Composition of the basal nutrient solution

Nutrient element	mg/kg soil
K as KCl or K-zeolite N	0, 2.8, 5.6, 11, 23, 45, 89
N as NH_4NO_3 (applied every two weeks)	96.37
Ca as CaCl_2	40.91
Mg (as MgSO_4)	3.94
Zn (as ZnSO_4)	3.25
Mn (as MnSO_4)	2.04
Cu (as CuSO_4)	0.51
B (as H_3BO_3)	0.12
Co as $\text{CoSO}_4 \cdot 7\text{H}_2\text{O}$	0.08
Mo as $\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$	0.08
S (as MgSO_4 , ZnSO_4 , MnSO_4 , CuSO_4)	34.20
Na (as Na_2MoO_4 and Na_2HPO_4)	30.44
P (as Na_2HPO_4)	20.50
Cl as CaCl_2 and KCl (only for reference pots)	72.44 (as CaCl_2), Maximum addition 81mg KCl

Figure captions

Figure 1a:

Amounts of K leached from pots supplied with KCl over time.

Figure 1b:

Amounts of K leached from pots supplied with K-zeolite N over time.

Figure 1c:

Cumulative % of added K leached from the pots supplied with KCl over time.

Figure 1d:

Cumulative % of added K leached from the pots supplied with K-zeolite N over time.

Figure 2a, b:

Average plant weight for non-leached and highly-leached pots plotted vs. K applied and (K applied - K leached), respectively.

Figure 3a:

The percentage of K in plants vs. K applied - K leached for non-leached and highly-leached pots.

Figure 3b:

Internal efficiency: K in plant vs. yield for non-leached and highly-leached pots.

Figure 3c:

Enlargement of the internal efficiency curves for highly-leached pots.

Figure 4 a-k:

The concentrations of elements in plants grown in highly-leached and non-leached pots vs. yield.

Figure 5a:

The distribution of K in plants and soil for non-leached pots.

Figure 5b:

The distribution of K in plants and soil for non-leached pots expressed on a percentage basis.

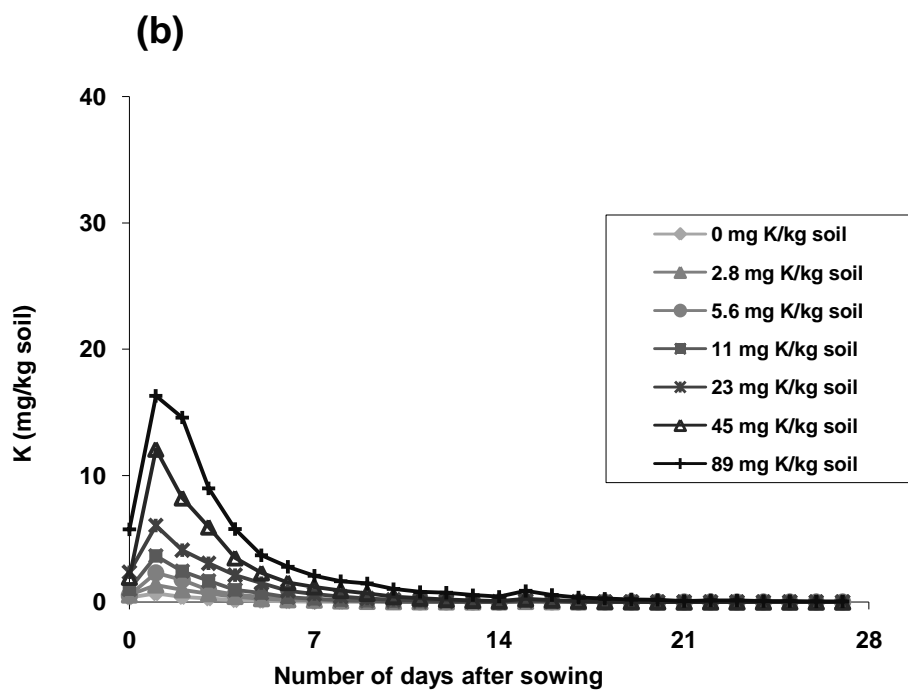
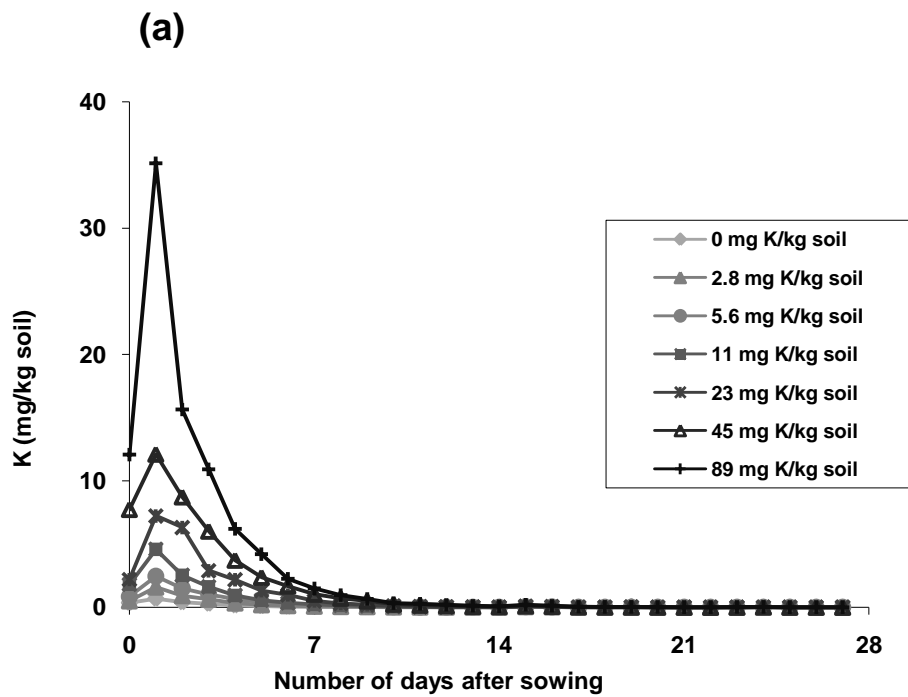
Figure 5c:

The distribution of K leached, K in plants and K remaining in soil for highly-leached pots.

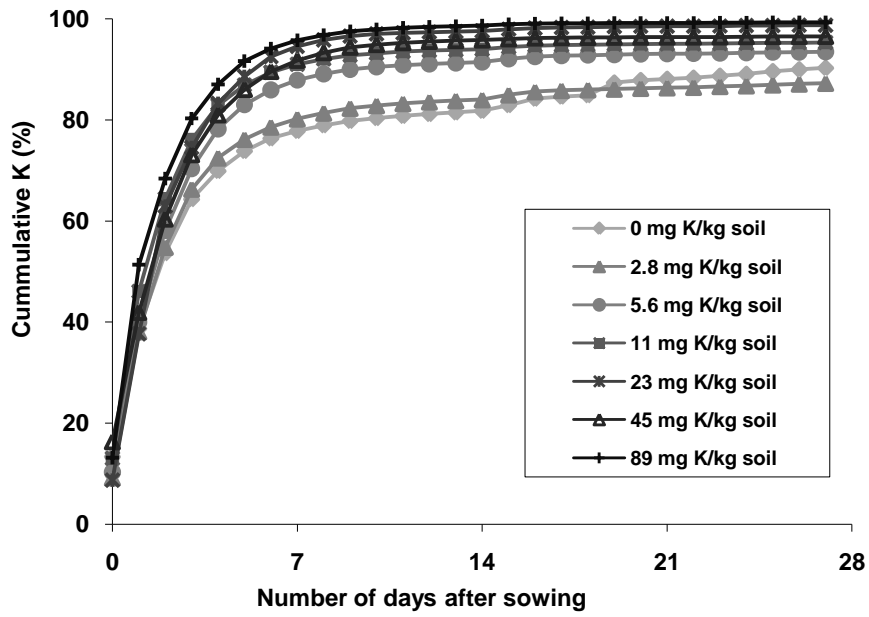
Figure 5d:

The distribution of K leached, K in plants and K remaining in soil for highly-leached pots expressed on a percentage basis.

Figure 1



(c)



(d)

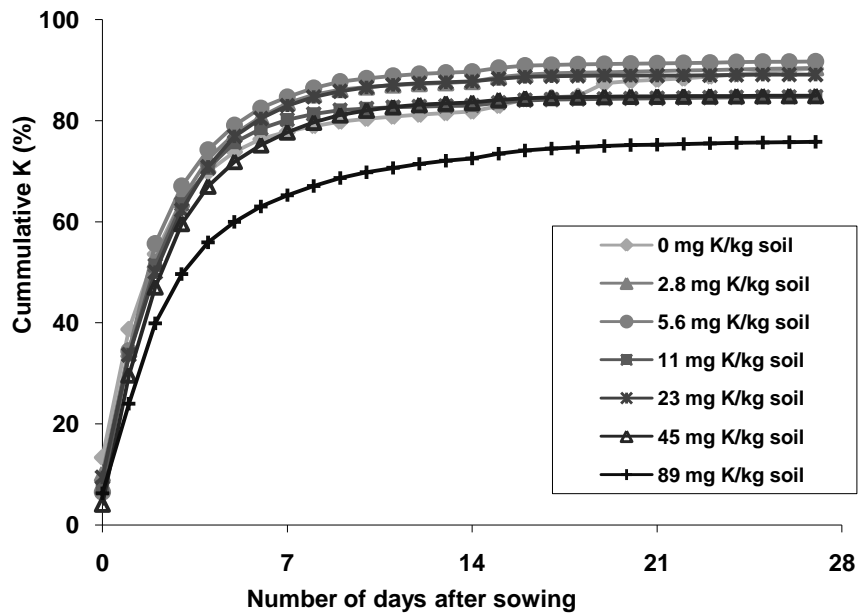
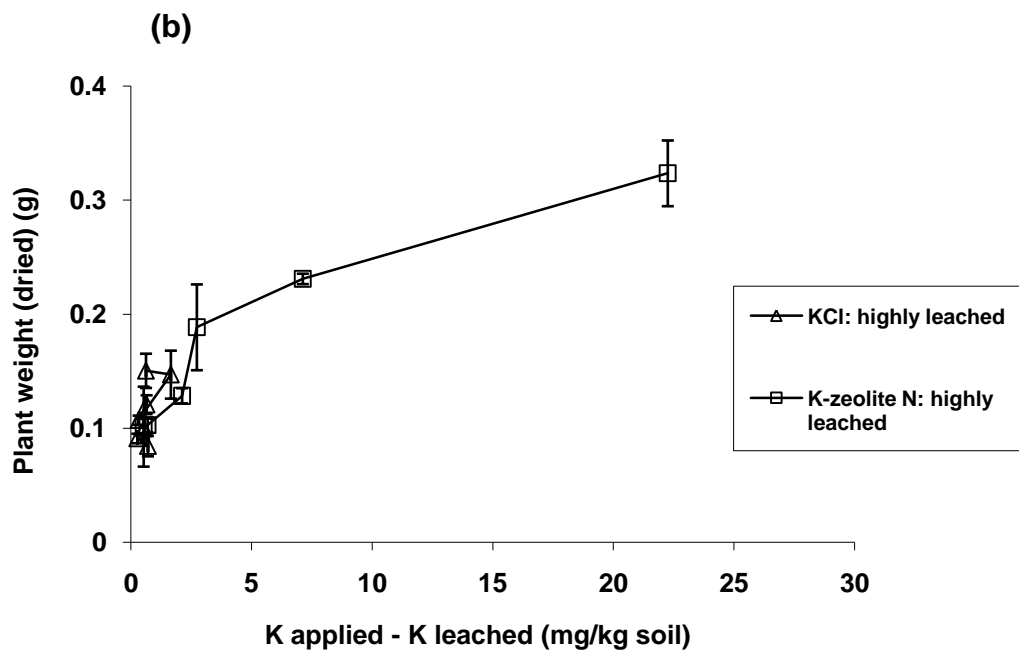
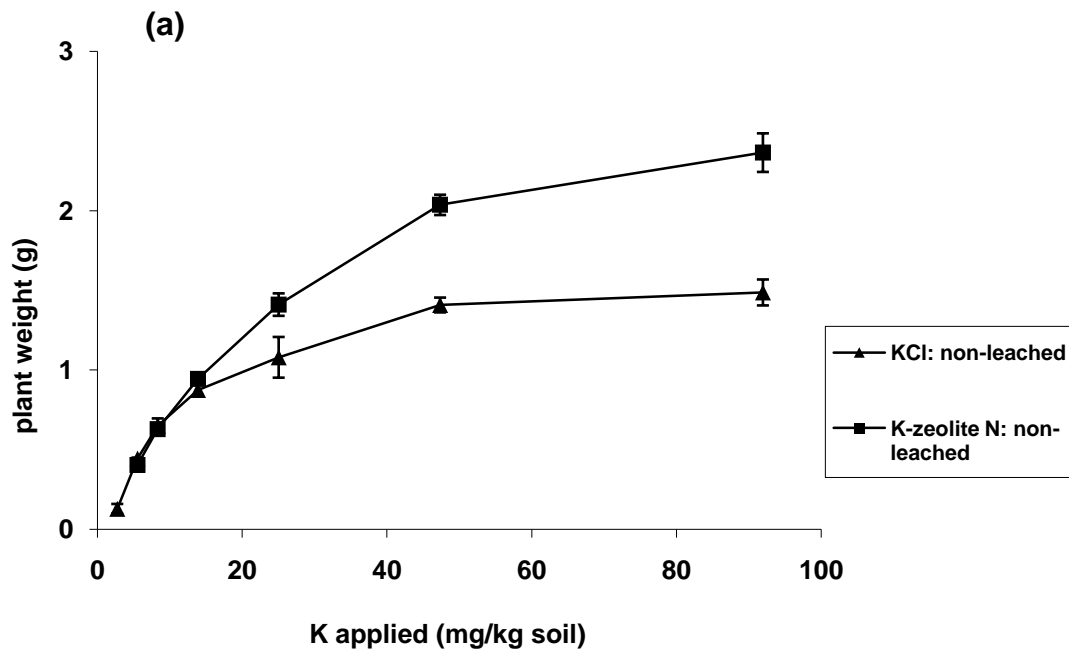
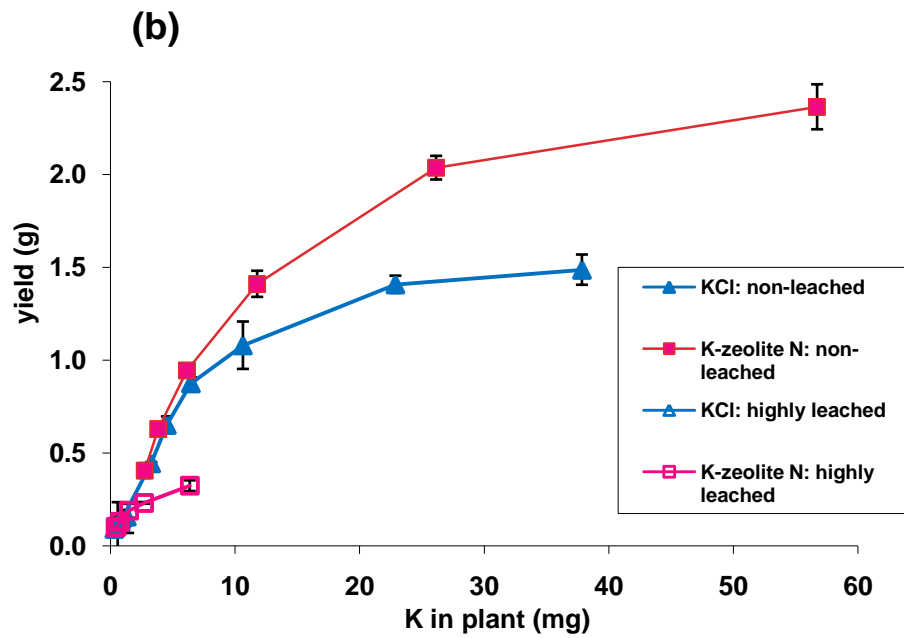
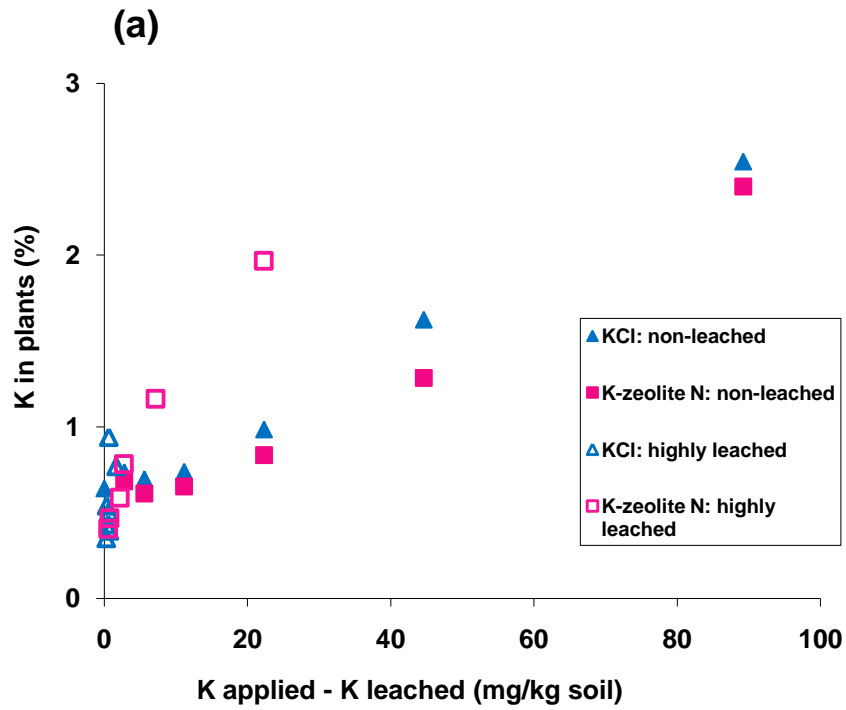


Figure 2 revised





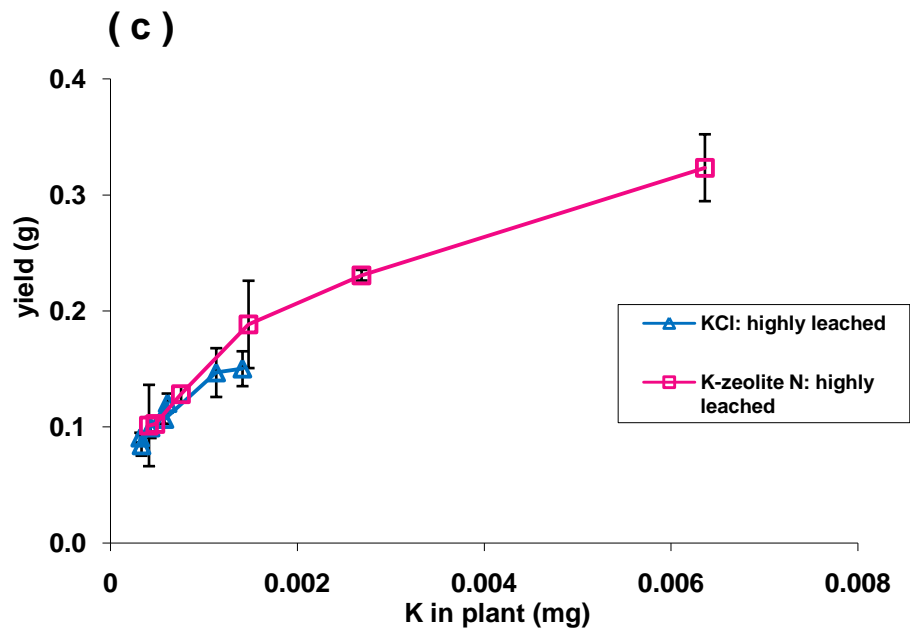


Figure 4

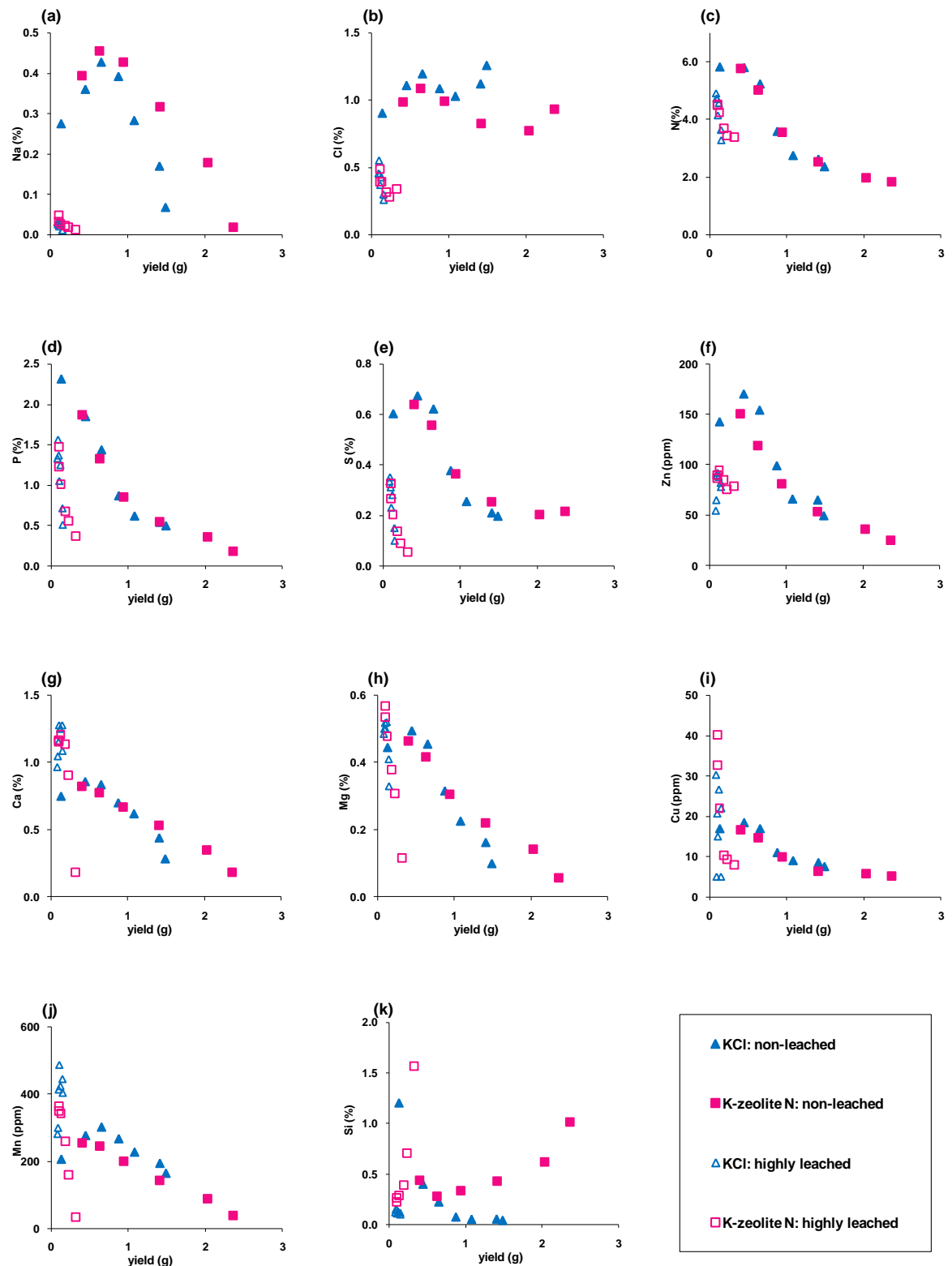


Figure 5 revised

