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1 **Estimation of Soil Clay Content from Hygroscopic Water Content Measurements**

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**ABSTRACT**

Soil texture and the soil water characteristic (SWC) are key properties used to estimate flow and transport parameters. Determination of clay content is therefore critical for understanding of plot scale soil heterogeneity. With increasing interest in proximal soil sensing, there is the need to relate obtained signals to soil properties of interest. Inference of soil texture, especially clay mineral content, from instrument response from electromagnetic induction and radiometric methods is of substantial interest. However, the cost of soil sampling and analysis required to link proximal measurements and soil properties, e.g. clay mineral content, can sometimes outweigh the benefits of using a fast proximal technique. In this paper, we propose that determination of a soil's hygroscopic water content at 50% atmospheric relative humidity ($RH^{50}$), which is time and cost efficient, and particularly suitable for developing countries, can act as a useful surrogate for clay content in interpreting soil spatial patterns based on proximal signals. We used standard clays such as kaolinite, illite and montmorillonite to determine the water release characteristic as a function of hygroscopic water content. We also determined clay content of soils from temperate (Arizona, USA) and tropical (Trinidad) regions using the hydrometer method, and hygroscopic water content for soils equilibrated at $RH^{50}$. We found linear dependence of clay percentage and $RH^{50}$ for a range of soil mineralogies. Hygroscopic water measurements offer an inexpensive and simple way to estimate site specific clay mineral content that in turn can be used to interpret geophysical signal data in reconnaissance surveys.

**Keywords**: Hygroscopic water, clay, water release curve, soil texture, geophysics, radiometrics, electromagnetic induction

47    **Abbreviations:** EMI, electromagnetic induction; RH, relative humidity; SWC, soil water

48    characteristic.

49

## INTRODUCTION

Soil texture (percentage of sand, silt and clay) is a fundamental parameter in soil science (Gee and Bauder, 1986) and a major component of the soil natural capital (Robinson et al., 2009a). Texture is widely used in agriculture and engineering as well as in basic research to estimate for example water release curves in flow and transport modeling (Schaap et al., 2001). Soil texture, especially clay content, controls magnitude and rates of many physical, chemical and hydrological processes in soils. Important soil phenomena such as nutrient storage, nutrient availability, water retention, and stability of aggregates may vary across the field in response to the spatial variability of clay percentage. Soil moisture which is the major control for rainfall-runoff response in a watershed (Robinson et al., 2008a) has been directly linked to clay variability (Crave and Gascuel-Odoux, 1997). Net nitrification and $CO_2$ release has been shown to depend on water content and clay content (Schjonning et al., 2003). Knowledge of texture, especially the spatial distribution of clay content, is therefore important for a range of ecosystem services, including provisioning through agricultural production and regulating of the hydrological cycle through filtering and buffering. A growing challenge in soil science is to map soil natural capital, of which texture is a component, in a way that allows us to scale from the soil profile, to field, to regions.

Proximal sensing techniques, especially geophysical sensors that infer spatial textural information from instrument response to ions adsorbed on clay minerals (Robinson et al., 2008b), provide an invaluable means for filling the 'intermediate' scale data gap. Electromagnetic induction (Doolittle et al., 1994; Triantafilis et al., 2001; Triantafilis and Lesch, 2005), resistivity (Samouelian et al., 2005), induced polarization (Slater et al., 2006) and radiometrics (Rawlins et al., 2007) are techniques progressively used to determine soil properties

73 or spatial patterns related to texture, inferred from mineralogy and cation binding. In case of

74 electrical methods, cations adsorbed to 2:1 clay minerals can be used to interpret, or determine,

75 the spatial pattern of clay percentage in non-saline soils (Triantafilis et al., 2001; Triantafilis and

76 Lesch, 2005; Sudduth et al., 2005; Harvey and Morgan, 2008). This method is limited to clays

77 that adsorb cations to counter balance negative charge sites, and is less likely to work for clay

78 minerals with low surface areas, e.g. kaolinites. In case of radiometrics, many clay minerals e.g.

79 hydrous micas and illites can be detected through their potassium isotope signal (Taylor et al.,

80 2002). Knowledge of clay content is therefore critical for the signal interpretation of proximal

81 sensing instruments.

82      Direct, grid-like soil sampling for identifying spatial textural patterns has several

83 limitations among which the need for high-intensity sampling and associated costs for analyses

84 are the most constraining ones. In addition, minimizing soil disturbance, i.e. not filling the

85 landscape with holes is vital for many hydrological process studies. In many cases, an

86 understanding of soil spatial patterns, and delimiting of hydrological functional units, is more

87 important than the exact knowledge of soil properties (Grayson and Blöschl, 2000). The costs for

88 independently measuring soil properties for calibration of proximal signals have always been an

89 issue, such that Lesch et al. (1995 a, b) developed efficient sampling methods for interpreting

90 EMI signal response from directed soil sampling. Even with approaches like theirs, the particle

91 size analysis presents a substantial cost for calibration, especially if multiple fields are sampled.

92      In this paper we propose that under many circumstances, a site specific calibration

93 between clay percentage and hygroscopic water content could be used to greatly reduce the

94 number of particle size analyses that might be done for a proximal sensing site calibration.

95 Estimating clay percentage from hygroscopic water content presents a cost efficient, simple and

96   reliable surrogate for correlating proximal signal response to soil clay content; although the

97   paper does not specifically explore EMI calibration. Our major goal is to investigate if simple,

98   cost and time efficient hygroscopic water content measurements can be used to estimate clay

99   contents for soils with varying mineralogies.

100      In soils, soil solution electrical conductivity $EC_e$, volumetric soil water $\theta_v$ and clay

101   contents are the major factors influencing bulk soil electrical conductivity $EC_a$ (Friedman, 2005)

102   and EMI signal response. In the case of radiometrics, clay content, and to a lesser extent soil

103   moisture are the driving factors. The intimate relationship between soil clay content and

104   hygroscopic water content is well established (Briggs and Shantz, 1912, Banin and Amiel, 1970;

105   Petersen et al., 1996), but not widely exploited. It was proposed as a method for determining soil

106   surface area, but largely abandoned because water tends to cluster on charged clay mineral

107   surfaces, not forming a monolayer like EGME, which has a lower dielectric constant, or non-

108   polar nitrogen (Quirk and Murray, 1999). Therefore, we hypothesize that soil hygroscopic water

109   content, whose determination is fast and technically less involved than particle size analysis,

110   positively correlates with clay percentage in both temperate and tropical soils, and can provide a

111   useful surrogate for soil clay content. Other research groups have presented results that

112   emphasize the strong correlation between hygroscopic water and clay contents (Banin and

113   Ameil, 1970; Petersen et al., 1996, Tuller and Or, 2005; Resurreccion et al., 2011), however,

114   there is no specific water potential or relative humidity agreed upon at which these relationships

115   should be determined.

116      Clay content and type of clay minerals determine the magnitude of the soil specific

117   surface area (Petersen et al., 1996). Banin and Amiel (1970) presented data with specific surface

118   area showing a strong linear dependence ($r^2$=0.902) to clay contents. In the studies of Banin and

119    Amiel (1970) and Dirksen and Dasberg (1993), hygroscopic water content had a strong linear

120    correlation ($r^2$=0.936) with soil specific surface area. Recently, Logsdon et al. (2010) determined

121    hygroscopic water content of soils in a vapor-tight container over distilled water at ~99 %

122    relative humidity and concluded that higher hygroscopic water content is associated with high

123    soil specific surface area. To come to an agreement about a specific relative humidity level at

124    which hygroscopic water content ought to be determined, in-depth knowledge of the water

125    release characteristics of different clay minerals is required. Therefore, the objectives of the

126    present study were to: (1) determine the water release characteristics for standard source clays;

127    (2) define a suitable relative humidity level for estimating clay content for the source clays; and

128    (3) examine the relationship between hygroscopic water content and clay content using the

129    defined relative humidity for soils with varying mineralogies from temperate and tropical

130    regions.

131

132    **MATERIALS AND METHODS**

133    **Clay Minerals**

134        Standard 100 % source clay minerals were used to determine the hygroscopic water

135    content as a function of relative humidity. The selected samples were the same as used in Lebron

136    et al. (2009) and included: Silver Hill illite from Montana (IMt-1) and Ca-montmorillonite from

137    Cheto, AZ (SAz-1) obtained from the Clay Mineral Society's Source Clay Repository; Wyoming

138    bentonite (Aqua Technologies of Wyoming, Casper); and kaolinite from the Lamar pit (Bath,

139    SC). The SAz-1 montmorillonite was saturated with Na, Ca or Mg to produce clay samples

140    saturated with a single ion (Goldberg and Glaubig, 1987).

141

**Soil Samples**

143        The first set of samples contained tropical soils from the University of the West Indies

144    soil sample collection in Trinidad. Trinidad is the southernmost of the Islands of the Lesser

145    Antilles in the Caribbean Sea and is situated $10^o3'$N $60^o55'$W and $10^o50'$N $61^o55'$W. The 23 soils

146    used for this study were collected from different locations across the island, representing a range

147    of soil types including kaolinitic, micaceous, and montmorillonitic soils (Table 1). In addition,

148    20 temperate soils from the University of Arizona Department of Soil, Water and Environmental

149    Sciences' source soil collection, again representing a wide range of mineralogies and clay

150    content were analyzed (Table 1).

151        Furthermore, a number of datasets originating from both Trinidad and the USA that were

152    previously used for EMI calibration were investigated. Soils from Trinidad were collected from

153    Guayaguayare, Moruga, Centeno and Woodland from locations identified via an EMI-directed

154    soil sampling method (Lesch et al., 2000). Data from the USA were obtained from the T.W.

155    Daniel Experimental Forest (TWDEF) in northern Utah and the Reynolds Mountain East

156    catchment within the Reynolds Creek Experimental Watershed in southwestern Idaho (Abdu et

157    al., 2008).

158

159    **Clay and Soil Sample Analysis**

160        The water release characteristics for the source clays were measured with a Dewpoint

161    Potentiameter (WP4-T, Decagon Devices, Inc., Pullman, WA, USA). The clay samples were

162    oven dried at $105^oC$ and then left equilibrating with the ambient laboratory atmosphere at

163    controlled temperature ($25^oC$) for several months. Once the humidity level of interest had been

164    reached and was stable for 2-3 days, samples were weighed with an analytical balance and the

165    soil water potential was determined with the WP4-T. Relative humidity was measured using a

166    humidity sensor (Thermo Hygro, Thermo-Fisher, Waltham, MA). In order to establish a range of

167    humidities this experiment lasted about 5 months. Soil water potential was converted to relative

168    humidity via the well-known Kelvin equation:

169
$$\Psi_w = \frac{RT\rho_w}{M_w} \ln\left(\frac{e}{e_0}\right) \tag{1}$$

170    where $\Psi_w$ is soil water potential, $R$ is the universal gas constant (8.31 J K$^{-1}$ mol$^{-1}$), $T$ is the

171    absolute temperature ($^o$K), $\rho_w$ is the density of water (kg m$^{-3}$) and $M_w$ is the molecular weight of

172    water (0.018 kg/mol). The ratio of e, the water vapor pressure, to $e_0$, the saturation vapor

173    pressure, is the temperature-dependent relative humidity, which can be rewritten as:

174
$$RH = \frac{e}{e_0} = \exp^{\frac{M_w \Psi_w}{\rho_w R T}} \tag{2}$$

175    The soil samples originating from Trinidad were first oven-dried at 105 $^o$C and then equilibrated

176    with the ambient atmosphere of a temperature-controlled room (25 $^o$C) with a monitored relative

177    humidity (Thermo Hygro, Thermo-Fisher, Waltham, MA) of ~50 %. The steps developed to

178    measure hygroscopic water content ($\theta_{hw}$) at RH$^{50}$ are described below:

179

180    1. Weigh the sample containers using a four-decimal analytical balance ($W_c$).

181    2. Weigh approximately 10 g of air-dried sample into the sample containers and place them in

182    the oven to dry at 105 $^o$C for 24 hours, weigh again directly from the oven before cooling, using

183    a thermal isolator to protect the balance ($W_{ovendry}$).

184   3. Allow the oven-dried samples to equilibrate to $RH^{50}$ at ambient conditions in the laboratory.

185   Equilibration of our samples was achieved within 48 to 72 hours when RH was monitored using

186   a thermohygrometer sensor.

187   4. Measure the humidity, monitor over a 2 hours period, if 50 % is maintained reweigh the

188   equilibrated samples to determine the moisture gain ($W_{RH50}$).

189   5. The $\theta_{hw}$ at $RH^{50}$ in the sample is calculated gravimetrically as:

190

191   $$\theta_{hw} = \frac{(W_{RH50} - W_c) - (W_{ovendry} - W_c)}{(W_{ovendry} - W_c)} \qquad (3)$$

192

193   The samples from Arizona were equilibrated at 50 % humidity and 25 $^{o}$C using a temperature

194   and humidity controlled environmental chamber (1007H Temperature/Humidity Chamber,

195   TestEquity, LLC, Moorpark, CA, USA). An additional experiment was conducted to determine

196   how fast soils re-adsorb water following oven-drying. To achieve this, oven-dried soil samples

197   were weighed and kept in the environmental chamber at 50 % relative humidity and 25 $^{o}$C. The

198   soil samples were then weighed in 3 hour intervals to capture the initially highly dynamic change

199   in water content. The time interval was then stepwise increased to 6, 12, and 24 hours for a total

200   time period of 15 days. The clay content was determined with the hydrometer method (Gee and

201   Bauder, 1986). Organic matter was removed using hydrogen peroxide (35 % $H_2O_2$) and

202   dispersed using 5 %-sodium hexametaphosphate.

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207 **RESULTS**

208 **Source Clay Samples**

209    Results for hygroscopic water content ($\theta_{hw}$) as a function of relative humidity are

210 presented in Fig. 1. The data for 2:1 clay minerals show a substantial increase in $\theta_{hw}$ at low

211 humidities, a levelling off at RH values between about 50-60 % and then increasing water

212 content again at RH values above 80 %. Both the 2:1 clays montmorillonite and illite adsorbed

213 more than 0.05 m$^3$ of water per gram of oven dry soil at RH values of ~50 %. However, kaolinite

214 didn't adsorb water until ~80 % humidity or higher.

215

216 **Determination of Hygroscopic Water Content at RH$^{50}$**

217    Based on results from the water release curves (Fig. 1) we adopted the RH$^{50}$ for

218 equilibrating our soils as a compromise value considering the range of mineralogies. This also

219 represents a relatively stable point at which the change of $\theta_{hw}$ with humidity is at a minimum;

220 RH$^{50}$ is also commonly attained in the laboratory meaning no special equipment is required to

221 equilibrate the soils at this humidity.

222

223 **Water Uptake and Equilibration of Samples at RH$^{50}$**

224    After adopting the RH$^{50}$ for equilibrating our soils, we determined the time for samples to

225 readsorb water in the lab following oven drying. The results of the rate at which water uptake

226 occur using the Arizona soils data set after oven drying is presented in Fig. 2. The facilities at the

227 laboratory in Arizona allowed samples to be analyzed in greater detail under more tightly

228 controlled conditions. In our experimental method soils are oven dried and then allowed to re-

229 equilibrate at RH$^{50}$ to determine the fraction of hygroscopic water. The samples tend to

230    equilibrate within ~2 days (Fig. 2). We suggest leaving the samples for a minimum of 54 hours,

231    which seems appropriate for re-equilibration. This is convenient for laboratory scheduling, as

232    soils may be removed from a drying oven, after drying overnight, and then be weighed with the

233    start of equilibration at ~9 am. Samples can be left to equilibrate for two days and then measured

234    around 3 pm or later to determine the water uptake.

235

236    **Effect of Organic Matter Removal on Water Adsorption at RH[50]**

237         Hygroscopic water content as a function of the clay percentage of untreated and treated

238    Arizona soils that have had organic matter removed are presented in Fig. 3. The purpose of this

239    was to determine if the presence of organic matter strongly affected the relationship between the

240    hygroscopic water content and clay percentage. The removal of organic matter results in slightly

241    lower water adsorption, confirming that the clay percentage is the major factor in determining

242    the amount of water adsorbed. Based on the regression lines shown, and assuming that the

243    organic matter is largely responsible for any additional water adsorption, ~5 % difference in

244    organic matter for a soil with ~50 % clay may result in an 8 % difference in the estimated clay

245    percentage, which is acceptable for using field soil for a reconnaissance survey. This indicates

246    that for these soils, organic matter was not a major issue, but in future work we might want to

247    examine how different types of organic matter adsorb water and whether the relationship is

248    linear.

249         Fig. 4 compares the measurement error associated with determining the hygroscopic

250    water content of soil samples based on mass gained, with the measurement error associated with

251    determining clay content from sedimentation analysis using the hydrometer method. As

252    expected, the measurement errors are generally smaller at higher clay contents, with the % error

253 increasing rapidly at low clay contents. The error for the hygroscopic water content is generally

254 lower at low clay contents because our ability to weigh accurately is greater than our ability to

255 detect clay via sedimentation at low clay contents; from clay contents of 10-50 % the errors

256 involved are similar. This indicates that the greatest errors in estimating clay percentage from

257 hygroscopic water will be dependent on the spatial variability of organic matter, if not removed

258 from samples.

259

260 **Hygroscopic Water Content as a Function of Clay Content for Soils Equilibrated at RH$^{50}$**

261 Hygroscopic water content as a function of clay percentage for both the Arizona and

262 Trinidad soil data sets equilibrated at RH$^{50}$ is presented in Fig. 5. The Trinidad soils are divided

263 according to major mineralogy, kaolinitic, micaceous and mixed clays, sesquioxides and

264 montmorillonitic; the Arizona soils were dominated by mica and illite clay minerals. These soils

265 represent the range of 2:1 and 1:1 clay mineralogies (Table 1) and indicate strong consistency in

266 response compared to the trendlines indicated for the different pure clay minerals. The soils

267 dominated by sesquioxides and montmorillonite have distinctively higher hygroscopic water

268 content values than the other soils. The montmorillonite follows the bentonite trendline, whilst

269 the micaceous and mixed mineralogy follows the illite trendline. Noticeably the oxide dominated

270 soil follows the bentonite trendline indicating this soil can adsorb a lot of water; highly

271 weathered tropical soils with amorphous oxides can have large surface areas on which water can

272 adsorb (Sanchez, 1976; Goldberg et al., 2001; Robinson et al., 2009b). In addition, some of the

273 kaolinitic soils (clay content 50-70 %) have higher water content than might be expected. This

274 may occur due to the presence of oxides in these soils, biasing values upwards and requires

275 further research. The r$^2$ values for the regression equations of hygroscopic water content as a

276    function of clay content were 0.78 and 0.68 for Arizona soils and all Trinidad soils, respectively.

277    This indicates a positive linear relationship between hygroscopic water content and clay content

278    for soils of varying mineralogies, from temperate and tropical regions. The relationship was only

279    superior in the Arizona soils compared to the Trinidad soils due to less mineralogical variation.

280    The $r^2$ for the Trinidad soils increased to 0.84 after removing the oxide and montmorillonite

281    soils.

282        A compilation of available data sets that contain both clay percentage information and

283    hygroscopic water content ($RH^{50}$) for samples taken from landscapes mapped with the EMI

284    sensor in the USA and Trinidad, are presented in Fig. 6.  The results fall broadly in the same

285    location as in Fig. 5. The $r^2$ values with intercept set to zero, RMSE and corresponding

286    mineralogy are presented in Table 2. The $r^2$ values improve as the range of the clay percentage

287    broadens. All RMSE values for clay percentage as a function of $RH^{50}$ fall below 10 % with the

288    median value being 5 %. This indicates that for these soils, $RH^{50}$ was a reasonable predictor of

289    clay percentage. Placing a regression line through all data (clay % = 1037.5* $RH^{50}$) gave an $r^2$ of

290    0.70 and resulted in a RMSE of 6.5 % which may be acceptable for reconnaissance survey.

291    However, we do not advocate the use of a single relationship as it is mineralogy dependent. In

292    this regard a site specific calibration should be established between $RH^{50}$ and clay percentage

293    that could then be used to estimate clay percentage from subsequent samples measured only for

294    $RH^{50}$. $RH^{50}$ values would be useful for providing secondary data, in for example co-kriging

295    geostatistical methods (Lesch et al., 1995a). The results indicate reasonable correlations,

296    demonstrating that hygroscopic water content at $RH^{50}$ has good potential to act as a pedotransfer

297    function to estimate clay percentage at least for reconnaissance surveys and as a secondary

298    variable for geostatistical interpolation.

**DISCUSSION**

Developing a standard approach to estimating clay percentage from the hygroscopic water content relies on agreeing on an accepted relative humidity value at which to measure the hygroscopic water content. Different authors have used different values, Banin and Amiel (1970) used air dry samples, whilst Petersen et al. (1996) used a pressure of 1.5 MPa. Logsdon et al. (2010) determined hygroscopic water content of air dry soils in a vapor-tight container over distilled water at ~99 % relative humidity. In an effort to standardize a method, Lebron et al. (2009), used a hygroscopic water content of 41 % to determine gypsum content in soils. They used 41 % because this is the relative humidity achieved by equilibrating samples over a saturated solution of $K_2CO_3$ in a dessicator, which makes standardization easier, especially given the temperature stability of the RH of $K_2CO_3$. However, finding a salt that offers a temperature stable RH at ~50-60% is not straightforward. Any chosen value of RH is a trade-off between having a zone of minimal relative change of slope of the water release curve of the soil (Fig. 1), and having enough water to obtain a meaningful measurement of hygroscopic water content. $RH^{50}$ was chosen as a compromise, bearing in mind this trade-off, which seems to work reasonably well even in kaolinitic soils. The use of $K_2CO_3$ is appealing and good for 2:1 clay mineral soils, but is not so good for kaolinitic soils which have essentially desorbed all their water at RH 41%.

The benefits of proximal sensing techniques in reconnaissance surveys have, to some extent, been undermined by the cost and tedious requirements for soil sampling and analysis of properties such as clay percentage required for their calibration. The removal of organic matter from the samples in the current study resulted in only minimal reduction in adsorbed water (Fig. 4). This signifies that in soils low organic matter, clay percentage is the major factor in

15

322     determining the amount of water adsorbed. Clay percentage has been shown by previous workers

323     to be strongly correlated with specific surface area and hygroscopic water content (e.g., Banin

324     and Amiel, 1970; Petersen et al., 1996; Robinson et al., 2002). However, hygroscopic water

325     content which is a quicker and cheaper soil property to measure is often not routinely collected

326     by soil surveys (Robinson et al., 2002). Since the amount of water adsorbed by a sample varies

327     depending on the ambient humidity, finding a suitable relative humidity for the equilibration of

328     soils is important for the determination of hygroscopic water content to speed up the

329     interpretation of geophysical signals. In our study, $RH^{50}$ was chosen as a compromise value from

330     the determination of hygroscopic water content for standard clays which generally yielded

331     hygroscopic water content values that were strongly correlated with clay percentage for both

332     tropical and temperate soils of varying mineralogies.

333

334

335     **SUMMARY AND CONCLUSIONS**

336

337        The work presented describes a simple, cost and time efficient method of estimating clay

338     content using hygroscopic water content measurements. To successfully determine the

339     relationship between hygroscopic water content and clay content it is important to identify a

340     suitable value of relative humidity for equilibration of soils. Based on our results on water

341     release curves of standard clay minerals, this value was identified to be ~50 %, a relatively stable

342     point at which the change in hygroscopic water content with humidity is at a minimum. This

343     value was then used to equilibrate soil samples from tropical (Trinidad) and temperate (Arizona)

344     regions exhibiting a wide range of soil mineralogy.

16

345        The work presented indicates positive correlations between soil hygroscopic water

346   content measured at $RH^{50}$ and the clay percentage in the soil. Hygroscopic water content

347   measured at $RH^{50}$ has good potential to act as a pedotransfer function to estimate clay percentage

348   for surveys. One of three approaches, with increasing accuracy, could be adopted:

349        1) estimate clay percentage from the linear hygroscopic water content calibration

350          presented for all soils.

351        2) perform a site specific calibration on a soil subsample between clay and relative

352          humidity.

353        3) perform a full calibration using particle size analysis.

354

355        With the growth of proximal sensing the first approach offers a cheap and rapid way to

356   estimate the dependence of soil geophysical signal response surfaces to hygroscopic water

357   content as a surrogate for soil clay percentage for reconnaissance survey. This may guide a

358   surveyor as to the major soil parameter contributing to the geophysical signal response.

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454

455

456 **Table 1. USDA textural class, clay percentage and mineralogy of 23 tropical soils from the**
457 **soil collection of the University of the West Indies, Trinidad and 20 temperate soils from**
458 **the soil collection of the University of Arizona, USA.**

459

| University of the West Indies soil collection | | | University of Arizona soil collection | | |
|---|---|---|---|---|---|
| USDA textural class | Clay content (%) | Clay minerals | USDA textural class | Clay content (%) | Clay minerals |
| Sandy Loam | 15 | Kaolinitic | Coarse Sand | 1 | - |
| Sandy Loam | 17 | Micaceous | Fine Sand | 2 | - |
| Sandy Loam | 18 | Kaolinitic | Loamy Coarse Sand | 6 | Micaceous |
| Sandy Loam | 19 | Micaceous | Loamy Sand | 10 | Micaceous |
| Sandy clay Loam | 27 | Micaceous | Loamy Fine Sand | 5 | Micaceous |
| Sandy clay Loam | 27 | Mixed | Fine Sandy Loam | 7 | Illitic |
| Sandy clay Loam | 29 | Kaolinitic | Sandy Loam | 15 | Micaceous |
| Sandy clay Loam | 29 | Kaolinitic | Fine Sandy Loam | 12 | Micaceous |
| Sandy clay Loam | 29 | Kaolinitic | Loam | 19 | Illitic |
| Sandy clay Loam | 29 | Kaolinitic | Silt Loam | 20 | Micaceous |
| Sandy clay Loam | 33 | Kaolinitic | Silt Loam | 20 | Micaceous |
| Sandy clay Loam | 35 | Mixed | Loam | 24 | Micaceous |
| Clay Loam | 35 | Mixed | Sandy Clay Loam | 25 | Micaceous |
| Sandy clay | 43 | Oxidic | Sandy Clay Loam | 31 | Micaceous |
| Clay | 45 | Mixed | Clay Loam | 36 | Micaceous |
| Clay | 51 | Mixed | Silty Clay Loam | 35 | Micaceous |
| Clay | 55 | Kaolinitic | Silty Clay Loam | 34 | Micaceous |
| Clay | 57 | Mixed | Silty Clay | 52 | Illitic |
| Clay | 63 | Kaolinitic | Clay | 54 | Illitic |
| Clay | 66 | Kaolinitic | Sandy Clay | 39 | Micaceous |
| Clay | 67 | Mixed | | | |
| Clay | 71 | Montmorillonitic | | | |
| Clay | 82 | Mixed | | | |

460

461 **Table 2. RMSE for the prediction of clay percentage from the RH$^{50}$ values for a selection of**

462 **soils and the dominant mineralogy.**

| Soil sampling location | r$^2$ (No. of samples) | Clay % RMSE | Dominant mineralogy |
|---|---|---|---|
| Moruga, Trinidad | 0.40 (40) | 6.6 | Mixed |
| Guayaguayare, Trinidad | 0.62 (46) | 4.0 | Kaolinitic |
| Woodland, Trinidad | 0.40 (67) | 9.0 | Montmorillonitic |
| Centeno, Trinidad | 0.87 (123) | 6.2 | Mixed |
| TW Daniels, Utah | 0.63 (15) | 3.5 | Montmorillonitic |
| Reynolds Creek, Idaho | 0.48 (17) | 4.2 | Montmorillonitic |

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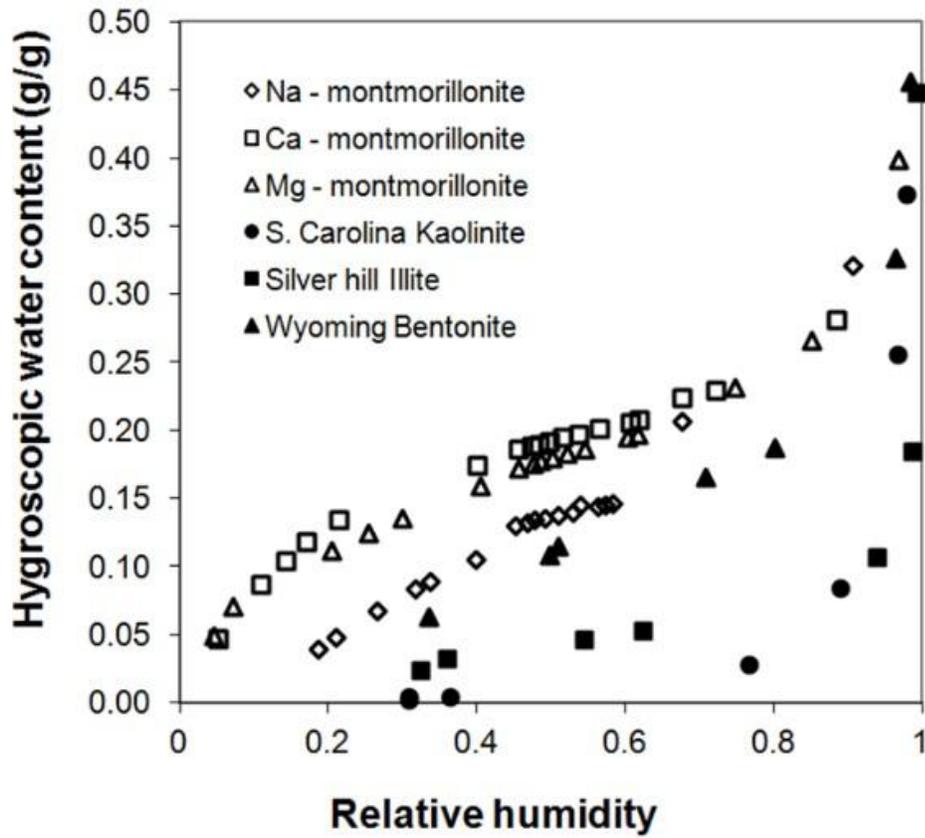
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466    Fig. 1. Water release curves for standard clays.

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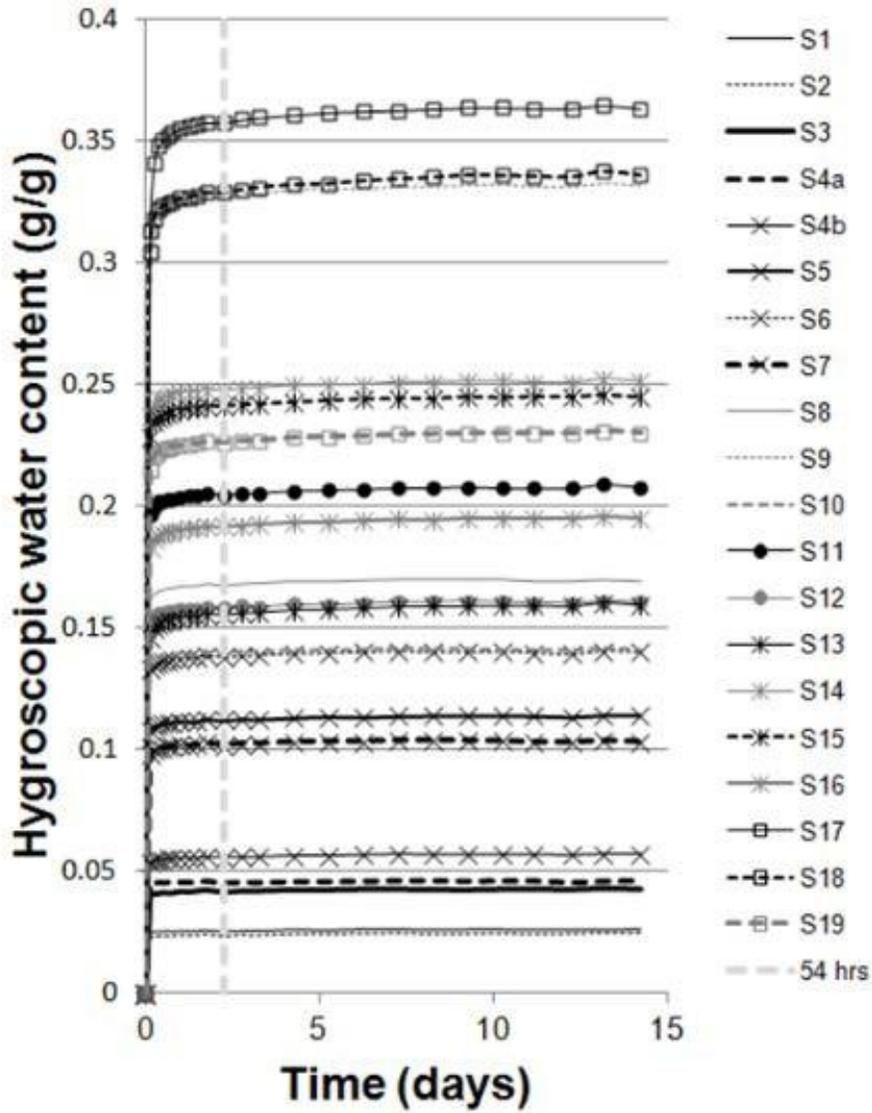
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471    Fig. 2. Water uptake on treated temperate Arizona soils at 25°C indicating water is rapidly

472    adsorbed in 48hrs.

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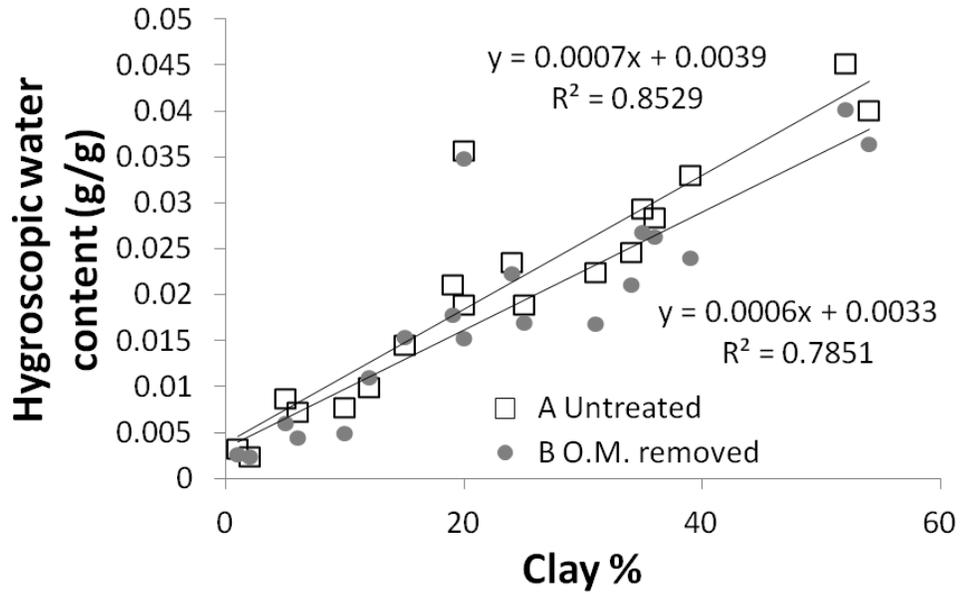
Fig. 3. Hygroscopic water content as a function of the clay percentage comparing untreated and treated temperate Arizona soils that have had organic matter (O.M.) removed.

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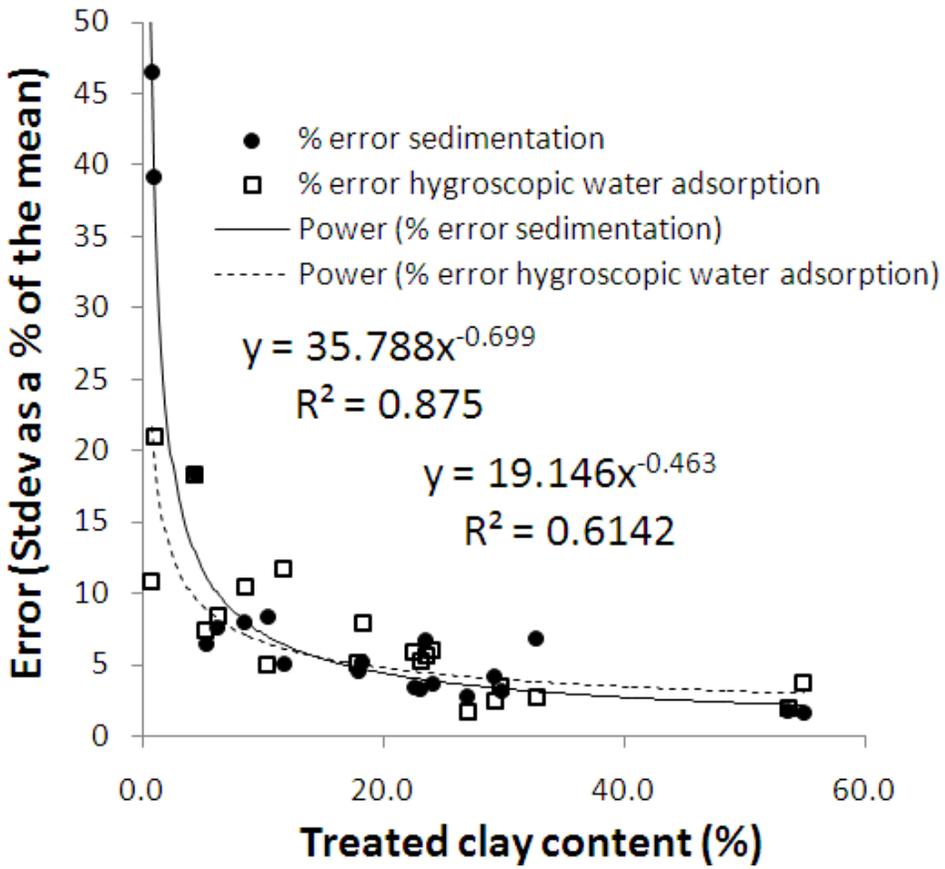


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482    Fig. 4. Trinidad and Arizona soils error as a function of the treated (organic matter removed) clay

483    percentage; the error is represented as the standard deviation (stdev) as a percentage of the mean

484    of 4 independent replicates.

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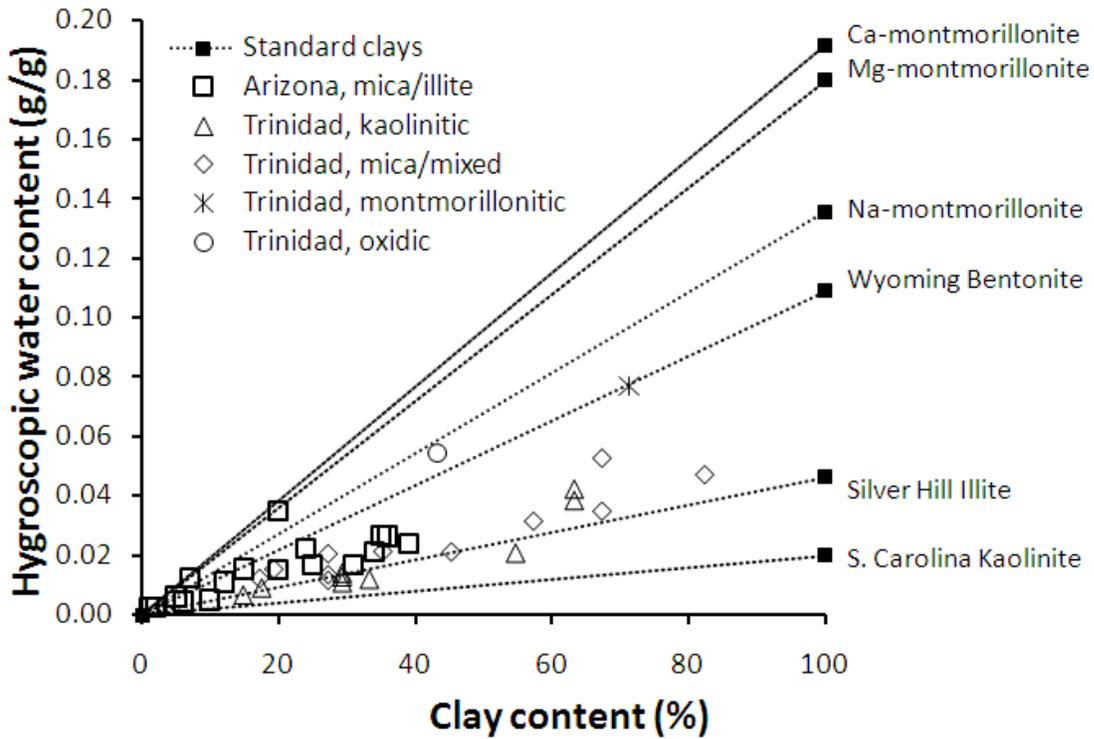


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489     Fig. 5. Hygroscopic water content ($RH^{50}$) as a function of clay percentage for 23 tropical

490     Trinidad soils divided by major mineralogy, 20 temperate Arizona soils, and 100 % clay

491     samples. The dashed linear trend lines join the 100% clay samples to the origin as a guide for

492     comparison with figure 6.

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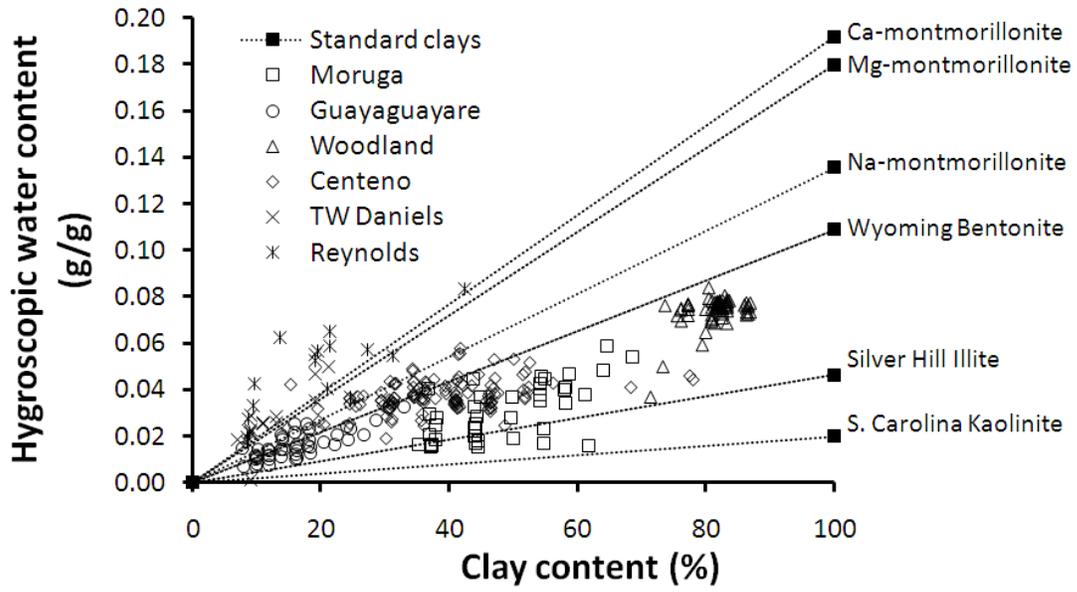
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498    Fig. 6. Five data sets showing field scale variability; one data set from a soil dominated by Ca

499    montmorillonite from Utah and four from Trinidad. The dashed linear trend lines join the 100%

500    clay samples to the origin as a guide for comparison with figure 5. For $r^2$ and RMSE see Table 2.