

## Evaluation of Kettler Simplified Method for Textural-Analysis of Different Arid-Region Soils

A.A. Moosavi\*, S. Karami and A. Moridi

Department of Soil Science, College of Agriculture, Shiraz University, Shiraz, Iran

\*Corresponding author, Email: aamousavi@gmail.com

### Abstract

Particle size distribution is a vital soil-component for assessing soil performance/behavior and soil-quality. Conventional-analyses are cost and time-consuming. Sands measured by sieving and clay and silt sized fractions are then usually measured by hydrometer or pipette-procedures. In 2001 Kettler et al. introduced a Rapid-method but till no there was no report about how does it work for different soil-types especially in arid/semi-arid regions. Therefore, the objective of this study was to evaluate this Rapid-method for textural-analysis of 8 textural-classes belonging to saline, calcareous, and gypsiferous soil types from arid and semiarid regions in comparison to standard-methods. Findings revealed that application of Rapid method resulted in the highest and the lowest accurate measurements (soil particles) in saline and gypsiferous soils, respectively. The highest determination coefficient ( $R^2=0.97$ ) and index of agreement ( $d=0.995$ ) were obtained between the results of Rapid and pipette-methods for saline-soils followed by calcareous, entire, and gypsiferous soil types, respectively. The measured clay and sand particles of studied soils using Rapid method were the most and the lowest accurate measurements, respectively (sand contents were overestimated). Applying Rapid method may lead to enough accurate measured primary particles in saline or calcareous soils; whereas, it cannot be recommended for gypsiferous soils. Besides, applying the Rapid method can result in more accurate measurements in finer textured soils than the coarser ones. In general, using the Kettler proposed Rapid method for textural analysis of fine textured saline or calcareous soils is recommended instead of the cost and time consuming methods of pipette or hydrometer.

**Keywords:** calcareous, gypsiferous, saline soils, Rapid method, pipette method, hydrometer method

### Introduction

Soil primary particles are divided into three major size classes of clay, silt and sand (particles with diameter of <0.002, 0.002- 0.05, 0.05-2.0 mm, respectively), based on the USDA classification system (Gee and Bauder, 1986). The relative proportion of the mentioned primary particles (sand, silt and clay) in a soil that is called soil texture is a vital component for assessing the suitability and quality of soil and sustainability of agricultural-management practices. The very wide variety of soil characteristics consisting of hydraulic, physical, chemical and biological

attributes influenced directly or indirectly by soil texture. For instance saturated and unsaturated hydraulic conductivity (Moosavi and Sepaskhah, 2012), soil-moisture retention curve (Saxton and Rawls, 2006), infiltration characteristics (Wakindiki and Ben-Hur, 2002), solute and material (fertilizers and pesticides,..) transportation within soil profile (Ozturk and Ozkan, 2002), soil erodibility and erosion potential (Wakindiki and Ben-Hur, 2002), soil fertility and nutrient availability, cation exchange capacity, soil organic matter content and dynamics, the capability of soil in carbon sequestration (Hassink, 1994) are influenced significantly by soil texture. In addition,

soil texture influences the ease with which soil can be worked, the amount of water and air it holds, and the rate at which water can enter and move through soil.

For evaluation of soil quality and sustainability of agricultural management practices, the soil textural analysis is a vital component of any minimum data-set to be used (Kettler et al., 2001). Conventional methods of soil textural analysis are often costly (7–18 \$ per sample, Kettler et al., 2001) and time-consuming (a time period of more than 24 h is needed, Gee and Bauder, 1986), requiring specific equipment and reagents (e.g., pipette, hydrometer, sedimentation 1000 ml glass cylinder, chronometer, electric mixer with dispersing cup, thermometer, sodium hexa-meta-phosphate or sodium hydroxide, etc), time, and resources to process samples by commercial or research laboratories. Further, the technology is not instantly attainable to agricultural experts, environmentalist, and experts working with producers (Kettler et al., 2001).

Following steps are required in soil textural analysis: 1) dispersing the soil into individual primary particles using a combination of chemical and mechanical approaches, and 2) fractionation and quantification of each particle-size interval by sieving or sedimentation approaches such as those accepted as standard methods for particle-size analysis i.e., the hydrometer and pipette methods (Gee and Bauder, 1986).

Chemical dispersion of soil into individual primary particles (sand, silt, and clay) in standard pipette and hydrometer procedures consist of adding hydrogen peroxide ( $H_2O_2$ ) to oxidize organic matter which binds primary soil particles into aggregates. Thereafter, sodium hexametaphosphate [ $NaPO_3)_n$ ] is used to complex  $Ca^{2+}$ ,  $Al^{3+}$ ,  $Fe^{3+}$ , and other cations in soil solution that bind clay and silt particles into aggregates and to replace aforementioned cations with  $Na^+$  on the ion-exchange complex of soil particles, resulting in dispersion of individual soil particles and breaking down of soil aggregates (Gee and Bauder, 1986 after Kettler et al., 2001). Mechanical dispersion by shaking with electrical or mechanical shakers used in combination to chemical treatments enhances the dispersion. Sieving and/or sedimentation procedures are used to fractionate each particle-size

interval after dispersion. Sieving is inefficient and difficult for particle of diameters less than 0.05 mm, therefore, sedimentation in water is the favorite procedure. In sedimentation, a suspension of the dispersed sample is allowed to settle, and measurements are made of the solution density at a specific depth and each predetermined periods of time (according to Stokes' Law) within the sedimentation cylinder (Gee and Bauder, 1986 after Kettler et al., 2001). Considering the abovementioned difficulties and time consumption nature of the standard pipette and hydrometer methods, a simplified rapid method for soil textural analysis introduced by Kettler et al. (2001). In the new Kettler proposed method the procedures was simplified and shorten (a total time period of 2 h is needed). Since the Kettler simplified Rapid method (Kettler et al., 2001) may work differently in various soil types, therefore, the objective of this study was to evaluate the simplified Rapid method of Kettler for assessing soil particle size distribution in different soil types of calcareous, gypsiferous and saline soils of southwestern IR Iran and also to compare the result of Rapid method to those of common standard methods of pipette and hydrometer.

## Materials and Methods

### Soil Samples Collection and Preparation

In order to evaluate the proposed simplified procedure for soil textural analysis (Kettler, 2001), different soil types including 12 calcareous, 10 gypsiferous and 9 saline soils (Table 1) were collected from 0-20 cm depth of Shiraz, Kazeroon and Ahvaz/Shiraz plains of IR Iran, respectively. Collected samples were taken to laboratory; air dried and passed through a 2 mm sieve. Soil textural analyses of each sample were performed using the Kettler simplified Rapid method (Kettler et al., 2001) with three replicates as well as with the standard methods of pipette and hydrometer as described in details in the following subsections.

### Textural Analysis Using Simplified Rapid Method of Kettler et al. (2001)

Kettler et al. (2001) suggested some changes in the common standard methods of hydrometer and pipette to propose their simplified Rapid method.

They recommended eliminating several steps to simplify the procedure. They suggested that the concentration of aqueous sodium hexameta-phosphate increased to 3%, and shaking time reduced to 2 h. There is no need to separate sand and particulate organic matter fractions of 0.5 to 2.0-mm range; therefore just the sand fraction of soil is collected using a 0.053-mm sieve. Using a lesser original soil mass of 15 g for the analysis, decrease the volume of water required to wash the clay and silt fractions through the sieve. The smaller volume of suspension can be collected in a 600-800-mL beaker, and the sedimentation step carried out without sub-sampling. The solution is mixed thoroughly to suspend all clay and silt particles, then allowed to settle undisturbed at room temperature of 18 to 24°C for a sedimentation period of at least 1.5 but <6 h. After sedimentation, the suspended clay fraction is decanted from the settled silt particles and discarded. The settled silt fraction is then dried in the beaker at 105°C to constant weight (Kettler et al., 2001). The sand, silt and clay percentage of soil were calculated based on their fractions of the original soil sample mass using the following equations:

$$\% \text{ Sand} = \frac{\text{Oven dry sand mass}}{\text{Soil sample mass}} \times 100 \quad (1)$$

$$\% \text{ Silt} = \frac{\text{Oven dry silt mass}}{\text{Soil sample mass}} \times 100 \quad (2)$$

$$\% \text{ Clay} = 100 - \% (\text{Sand} + \text{Silt}) \quad (3)$$

### Textural Analysis Using Standard Pipette Method

The pipette method similar to hydrometer method is based on the Stokes' Law. But in this standard method separation (dispersion) of soil particles is done more than that of hydrometer methods. Due to the more completed dispersion the precision of pipette measurements is much more than those of hydrometer, but it needs much more time to do. In order to determine the percentage of primary particles, 10 g of air-dried soil sample passed through the sieve of 1 mm radii openings (No. 200 sieve) weighed out exactly. The soil organic matter was removed by oxidation method with application of hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) one or more than one times to ensure there is no organic

matter in soil sample. Calcium and magnesium carbonates were removed from the soil sample with application of 100 mL 0.5N HCl and leaching with tap water in a Buchner funnel. Subsequently, that chemical dispersion of soil particles was carried out with addition of NaOH 1N till the pink color was created in the presence of phenol-phetalein. The suspension shaken by a mechanical shaker for a cumulative period of 24 hours over more than 2 days. The dispersed suspension passed through a sieve of 0.025 mm radii openings. Content of sand particles were determined by weighting the oven-dried particles remained on the sieve. The collected suspension below the sieve transferred to the standard sedimentation cylinder and tap water was added to fill the cylinder to the 1000 mL mark. The sedimentation cylinder was capped with rubber stopper and carefully agitated for about 1 min by turning the cylinder upside down and back movements. Two 25 mL samples were taken from the depth of 5 cm below the suspension surface with a pipette immediately (correspond to presence of both silt and clay content in the suspension) and 230 minute (correspond to presence of clay content in the suspension) after settlement of cylinder (Gee and Bauder, 1986). The weights of oven dried collected samples that correspond to the aforementioned times after settlement was determined and the percentage of soil primary particles was calculated using the following relations:

$$\% \text{ Sand} = \frac{M_{\text{sand}}}{M_{\text{soil}}} \times 100 \quad (4)$$

$$\% (\text{Silt} + \text{clay}) = \frac{M_{\text{sus}}}{M_{\text{soil}}} \times 100 \quad (5)$$

$$\% \text{ Clay} = \frac{M_{\text{sus-dry}}}{M_{\text{soil}}} \times 100 \quad (6)$$

Where

- $M_{\text{sand}}$  = mass of oven dried sand
- $M_{\text{soil}}$  = mass of soil sample remained  
( $M_{\text{sand}} + 40(\text{mass of clay} + \text{mass of silt})$ )
- $M_{\text{sus}}$  = mass of oven dried suspension immediately collected after settlement
- $M_{\text{sus-dry}}$  = mass of oven dried suspension collected 230 min after settlement

### Textural Analysis Using Hydrometer Method

The hydrometer analysis is based on the Stokes' Law, which gives the relationship among the velocity of fall of spheres in a fluid, the diameter and the specific weights of the sphere, the specific weights of fluid, and the fluid viscosity. In order to determine the percentage of silt and clay, 50 g of each air-dried soil sample passed through the sieve of 1 mm radii openings (No. 200 sieve) weighed out exactly. The soil organic matter (as a cementing agent) was removed by oxidation method with application of hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>). Chemical dispersion of soil particles was carried out by exposing to 100 mL of 5% sodium hexameta-phosphate for a 12 to 24 h period of time. At the end of the soaking period, the mixture was transferred to a dispersion cup and tap water was added until the cup was about two-thirds full. Soil suspension was mixed for 1 min by electronic mixture. After mixing, all the contents of the dispersion cup carefully transferred to the sedimentation cylinder. Then tap water was added to fill the cylinder to the 1000 mL mark. The sedimentation cylinder was capped with rubber stopper and carefully agitated for about 1 min by turning the cylinder upside down and back movements. The sedimentation cylinder was put beside the control cylinder and the stopwatch started immediately. The hydrometer inserted into the sedimentation cylinder and hydrometer readings were taken at cumulative times of 40 sec and 2 h by reading the upper level of meniscus. The temperature readings at all of the aforementioned cumulative times were taken by inserting a thermometer into sedimentation cylinder. The same procedure was done in the control jar. The control jar was prepared by adding 125 mL of 4% sodium hexa-meta-phosphate solution and sufficient distilled water to produce 1000 mL (Gee and Bauder, 1986). The percentage of soil particles were calculated based on their fractions in the soil sample using the following equations:

$$\% \text{ Clay} = \frac{\text{CHR at 2 h}}{\text{Soil sample mass}} \times 100 \quad (7)$$

where CHR is the corrected hydrometer reading that is determined using the regarding of hydrometer in control sedimentation cylinder

(SHR) and the recorded temperature (T, °C) at the time of hydrometer reading.

$$\text{CHR} = \text{HR} - \text{SHR} + 0.36 (T - 20) \quad (8)$$

$$\% \text{ Clay} = 100 - \frac{\text{CHR at 40 sec}}{\text{Soil sample mass}} \times 100 \quad (9)$$

$$\% \text{ Sand} = 100 - \% (\text{Silt} + \text{Clay}) \quad (10)$$

It should be pointed out that the more detailed instructions for both of pipette and hydrometer procedures can be seen in Gee and Bauder (1986) and in the other relevant references.

### Evaluation of Results

Accuracy of the primary particle fractions measured by Rapid method was evaluated by comparison with those of obtained using the standard method of pipette. The results of Rapid and pipette methods were also compared with those of common hydrometer method. Linear regression relationships were provided between each primary particle size classes and their coefficient of determination (R<sup>2</sup>) or correlation coefficient (r) was calculated as an index of judgment about the precision of aforementioned Rapid method in comparison to those of pipette or hydrometer methods. In addition, the index of agreement (d) between the results of applied Rapid method and pipette or hydrometer methods as another index of accuracy evaluation was calculated for each measured primary particles of soil using the following equation (Willmott, 1982):

$$d = 1 - \left[ \frac{\sum_{i=1}^n (P_i - \hat{P}_i)^2}{\sum_{i=1}^n (|P_i| + |\hat{P}_i|)^2} \right] \quad (11)$$

where d is the index of agreement that vary between 0 and 1 for the lowest and the highest agreements between the measured values using two applied methods e.g., Rapid and pipette or Rapid and hydrometer methods, respectively. P<sub>i</sub>' and  $\hat{P}_i$  are calculated using the following equations:

$$P_i' = P_i - \bar{P}_i \quad (12)$$

$$\hat{P}_i' = \hat{P}_i - \bar{P}_i \quad (13)$$

where  $\bar{P}_i$  is the mean value of each measured particle (%) using the standard method,  $P_i$  is the measured particle (%) using the applied method that we want to compare it with the standard method.

## Results and Discussion

The 31 soils used in the present study represented a wide range of clayey to sandy loam-textured soils based on the USDA instructions (Soil Survey Staff, 1999). Clay content varied from 2 to 95% and sand varied from 1 to 69% to produce eight soil textural classes ranging from clay to sandy loam (Table 1).

Results showed that the absolute differences for clay, silt and sand contents between pipette and Rapid methods for entire 31 studied soils ranged from 28 to 35, 38 to 42, and 17 to 34%, respectively. The mean values of aforementioned differences were 2, 4 and 5%, respectively. Whereas, separation of calcareous, gypsiferous, and saline soils resulted in absolute differences for clay, silt and sand contents between pipette and Rapid methods from 10 to 16, 14 to 19, and 14 to 17 % with the average differences of 2, 1 and 3 % in calcareous soils, respectively. The aforementioned differences were 28 to 35, 38 to 42, and 17 to 34% with the average values of 3, 6 and 8%, for gypsiferous soils and were 5 to 12, 2 to 15, and 6-18% with the average values of 1, 5 and 6% for saline soils, respectively. Findings of this study demonstrated that clay particles of entire soil samples measured by Kettler (2001) proposed Rapid method were the most accurate among the measured soil particles. Whereas, sand contents that measured by Rapid method were the least accurate measurements. In another word, the lowest and highest values of absolute differences between the results of pipette and Rapid methods were obtained for clay and sand particles, respectively. Results also revealed that the amounts of sand particles were overestimated with application of Rapid

method as compared to that of pipette. It means that the Rapid method resulted in coarser textured classes than pipette. Overestimation of sand may correspond to incomplete dispersion of soil particles in Rapid method. In another word incomplete dispersion of soil particles may result in take some flocculated clay or silt particles into consideration as sand particles.

In all of studied soil types, application of Rapid method resulted in the greater amounts of sand (coarser textured classes) than pipette method. Findings demonstrated that the measured soil particles of saline and gypsiferous soils using Rapid method were the most and the least accurate measurements in comparison to that of pipette method, respectively. Clay-sized particles (<0.002 mm) in gypsiferous soils were greatly underestimated when Rapid method was used as compared to those of pipette method. Gypsum can flocculate the primary particles of soils resulting in the greater amounts of sand than silt or clay contents for Rapid method in which the dispersion of soil particles is incomplete. Porta (1998) stated that determination of particle-size distribution of gypsiferous soils is problematic if standard methods of soil analysis are used. He concluded that gypsum acts as flocculating agent due to its semi-soluble nature. Therefore, a stable suspension of clay and silt cannot be achieved; in addition, the lower density and the shape of its crystal and existence of water in it (Hesse, 1976; Porta et al., 1986 and Poch, 1992 after Porta, 1998) result in difficulties in techniques of particle size analysis. He believed that when gypsum is a main component of the soil, its removal leads to meaningless results that uncorrelated to the actual physical behavior of the soil. Porta (1998) concluded that the gypsum content of soil may be very low (< 10%) and not significantly change the soil texture in many cases, but still causing flocculation during determination of particle size distribution. In these circumstances, removal of gypsum prior to particle size distribution have been introduced as the best approach (Porta, 1998) as proposed by some of investigators like Stern et al. (1989) and Rivers et al. (1982) in details.

**Table 1** General properties of studied soil types along with their measured primary particles using the simplified Rapid method and the standard methods of pipette and hydrometer.

Location/soil series	Classification <sup>1/</sup>	pH	EC (dS m <sup>-1</sup> )	OM (%)	Status	Particle Size Distribution (%)									Text <sup>2/</sup>
						Pipette method			Hydrometer method			Rapid method			
						Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay	
1 Ramjerdi 1	Fluentic Xerochrepts	7.6	0.68	2.3	Calcareous	1	91	8	3	90	7	7	83	10	Si
2 Kooye-Asatid 1	Fluentic Xerorthents	7.7	0.22	3.1	Calcareous	15	50	35	18	46	36	14	56	30	SiCL
3 Ramjerdi 2	Fluentic Xerochrepts	7.5	0.40	2.3	Calcareous	18	7	75	20	9	71	30	10	60	C
4 Bamoo 1	Typic Xerorthents	7.4	0.10	2.4	Calcareous	52	22	26	51	21	28	51	26	23	SCL
5 Shekarbani 1	Typic Xerorthents	7.6	0.30	2.4	Calcareous	30	50	20	32	48	20	29	48	23	SiL
6 Ramjerdi 3	Fluentic Xerochrepts	7.3	0.27	1.8	Calcareous	47	12	41	40	20	40	30	31	39	SC
7 Pompe-Namazi 1	Fluentic Xerochrepts	7.6	0.72	1.6	Calcareous	21	29	49	22	32	46	16	25	59	C
8 Pompe-Namazi 2	Fluentic Xerochrepts	7.5	0.66	2.8	Calcareous	2	63	36	4	60	36	8	63	29	SiCL
9 Kooye-Asatid 2	Fluentic Xerorthents	7.2	0.75	4.8	Calcareous	12	84	4	15	75	10	24	70	6	SiL
10 Bamoo 2	Typic Xerorthents	7.6	0.22	1.5	Calcareous	1	86	13	5	80	15	3	81	16	SiL
11 Ramjerdi 4	Fluentic Xerochrepts	7.4	0.40	4.4	Calcareous	12	60	29	15	60	25	26	62	13	SiCL
12 Kooye-Asatid 3	Fluentic Xerorthents	7.5	0.40	2.6	Calcareous	15	71	14	16	68	17	20	61	19	SiL
13 Kamaranj 1	Gypsic Haplusteps	7.2	1.17	1.6	Gypsiferous	49	50	2	46	26	28	49	22	30	SL
14 Kazeroon 1	Gypsic Haplusteps	7.0	1.19	1.4	Gypsiferous	64	10	26	50	33	17	47	37	16	SCL
15 Kazeroon 2	Gypsic Haplusteps	7.2	0.70	1.2	Gypsiferous	69	19	12	65	19	17	70	13	18	SL
16 Kamaranj 2	Gypsic Haplusteps	7.0	0.26	1.7	Gypsiferous	50	15	35	50	18	32	56	20	25	SC
17 Dadian1	Gypsic Haplusteps	7.2	2.11	0.8	Gypsiferous	20	73	7	48	33	19	53	36	12	SiL
18 Booshehr 1	Typic Torriorthents	7.1	0.43	1.9	Gypsiferous	27	60	13	30	40	30	27	39	36	SiL
19 Booshehr 2	Typic Torriorthents	7.3	2.62	2.6	Gypsiferous	42	10	49	42	49	9	40	48	14	C
20 Kamaranj 3	Gypsic Haplusteps	7.3	1.34	1.5	Gypsiferous	23	39	39	40	50	10	38	52	12	CL
21 Dadian 2	Gypsic Haplusteps	7.1	2.01	1.7	Gypsiferous	24	59	17	41	44	15	38	45	12	SiL
22 Kamaranj 4	Gypsic Haplusteps	7.2	2.31	2.6	Gypsiferous	19	73	8	59	30	11	53	32	3	SiL
23 Ahvaz 1	Typic Haplusteps	7.5	53.0	1.7	Saline	57	31	12	67	20	13	63	27	10	SL
24 Ahvaz 2	Typic Haplusteps	7.6	4.33	1.5	Saline	7	82	11	10	80	10	6	78	16	SiL
25 Ahvaz 3	Typic Haplusteps	7.4	6.54	1.9	Saline	36	48	16	35	50	15	30	50	20	L
26 Ahvaz 4	Typic Haplusteps	7.8	8.83	1.3	Saline	25	70	6	20	72	8	33	58	9	SiL
27 Moharloo 1	Typic Haplosalids	7.1	9.71	1.3	Saline	1	96	3	1	95	3	6	88	6	Si
28 Moharloo 2	Typic Haplosalids	7.9	88.3	2.9	Saline	19	24	57	26	20	54	37	18	45	C
29 Moharloo 3	Typic Haplosalids	7.8	88.3	0.6	Saline	2	3	95	5	5	90	6	5	89	C
30 Moharloo 4	Typic Haploxeralfs	7.8	24.7	0.5	Saline	4	85	11	7	80	13	18	70	12	SiL
31 Moharloo 5	Typic Haploxeralfs	7.4	8.25	0.4	Saline	32	38	30	29	44	27	35	39	27	CL

<sup>1/</sup> Soil classification according to Soil Taxonomy (Soil Survey Staff, 1999 after Khormali 2003, Jafari, 2005, Hashemi, 2010, and Khormouji, 2013).<sup>2/</sup> Text.: textural class–Clay, CL–Clay Loam, SC–Sandy Clay, SCL–Sandy Clay Loam, SL–Sandy Loam, Si–Silt, SiCL–Silty Clay Loam, SiL–Silt Loam.

**Regression Equations**

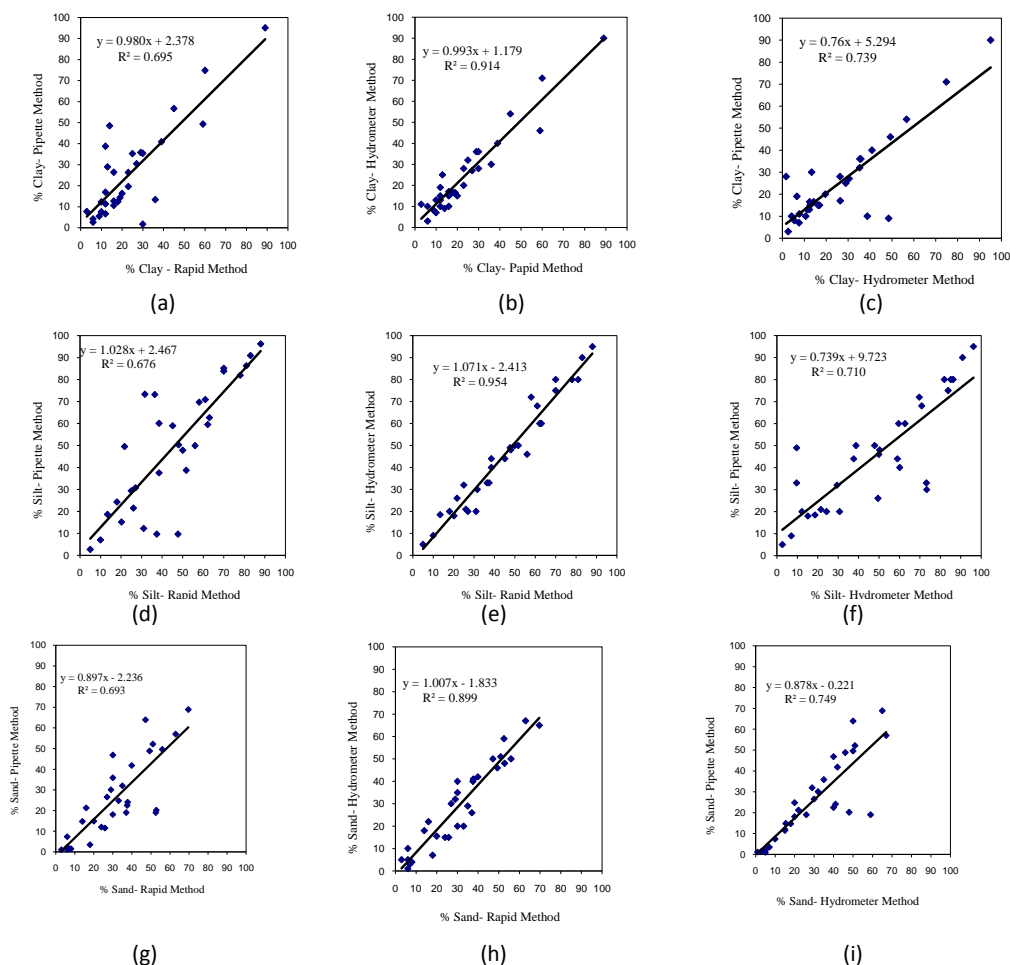
**Entire soil samples**

The soil primary particle fractions as measured by the Kettler (2001) proposed Rapid method were related to those measured by standard sedimentation methods of pipette and hydrometer using regression analysis (Figure 1). Separate regressions were also made for particle size classes of <0.002, 0.002-0.05, and 0.05-2 mm in studied soil types (Figures 2 to 4). The aforementioned particle size classes were selected to provide information needed to determine the soil textural classes as defined by the USDA (Soil Survey Staff, 1993).

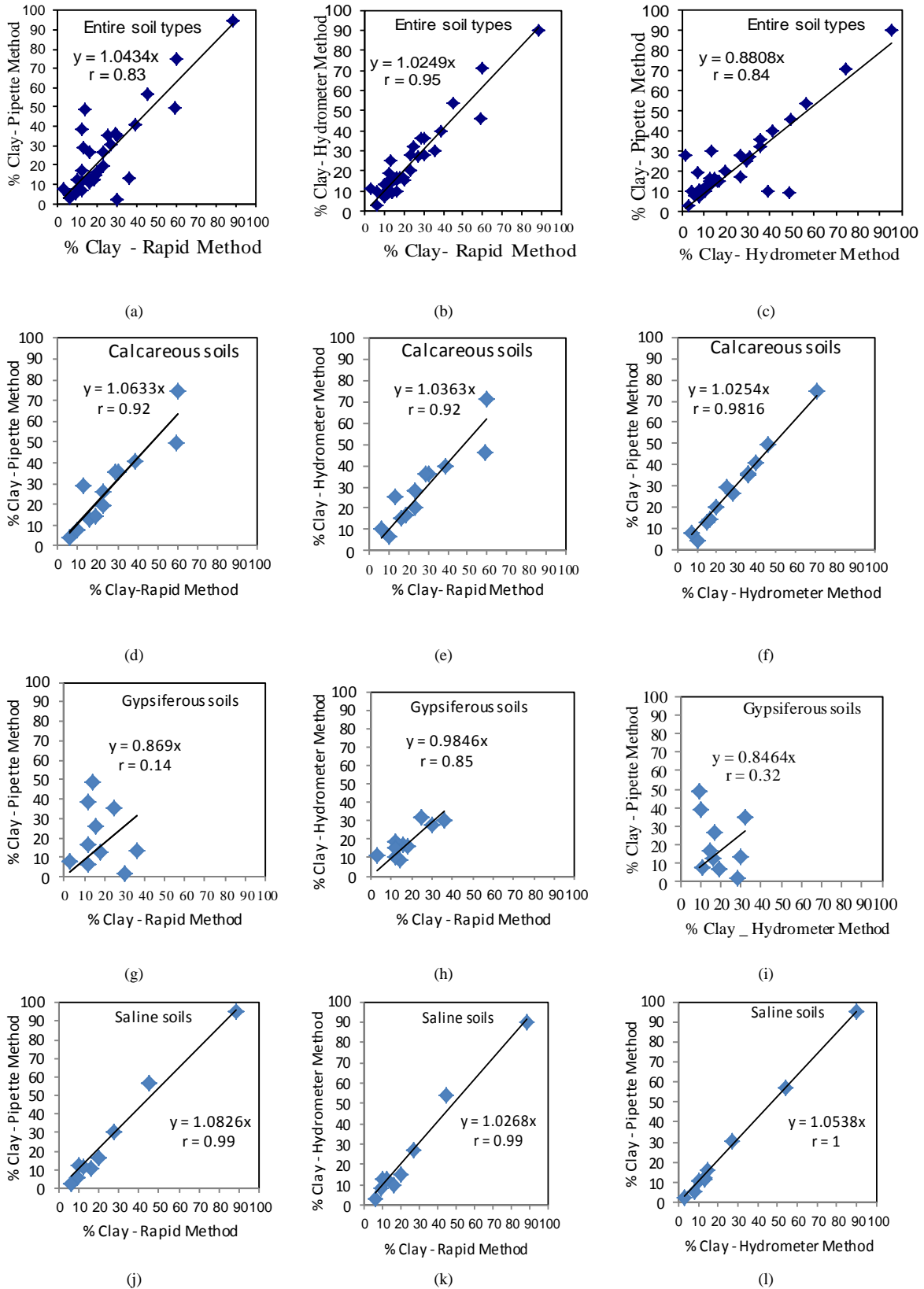
Regression equations between the results of Rapid and pipette methods showed that these two methods worked slightly different for determining all of soil particle classes; whereas, the results of Rapid and hydrometer methods was statistically similar. Therefore, in common applications in

which there is no need to high amount of precision, the Kettler (2001) proposed Rapid method can be used instead of time-consuming method of hydrometer.

Comparison of regression equations between the results of Rapid and pipette methods for measured clay, silt or sand contents were not statistically different at the probability level of 0.05 (Figure 1). In another word, the precision of Rapid method for determining all of soil primary particles were the same. The coefficient of determinations ( $R^2$ ) between the results of Rapid and pipette methods were 0.70, 0.68, and 0.69 for clay, silt, and sand particles, respectively which were not statistically different ( $P < 0.05$ ). While, the intercept values of regression equations between the results of pipette and hydrometer methods for measured silt or clay contents was significantly ( $P < 0.05$ ) more than that of measured sand contents.



**Figure 1** Regression relationships between the measured primary particles of clay (a to c), silt (d to f) and sand (g to i) for entire studied soil types using Rapid, pipette and hydrometer methods (the  $R^2$  values of <0.5 is statistically non-significant and  $R^2$  values of 0.5 to 0.74 and those of greater than 0.74 are statistically significant at the probability levels of 0.05 and 0.01, respectively).



**Figure 2** Regression relationships between the measured clay particles of studied soil types using different applied methods (the r values of <0.65 is statistically non-significant and r values of 0.65 to 0.9 and those of greater than 0.9 are statistically significant at the probability levels of 0.05 and 0.01, respectively).

Plots of the mean values of sand, silt, and clay contents for all of studied soil types measured by Rapid and hydrometer methods against the pipette method have been shown in Figure 1. Regression analysis for the results of Rapid method against the pipette for clay content of all studied soil types showed that the Rapid method produced relatively more accurate results  $\text{Clay}_{\text{pipette}} = 0.98\text{Clay}_{\text{rapid}} + 2.378$  ( $R^2=0.70^*$ ) than hydrometer method ( $\text{Clay}_{\text{pipette}} = 0.98\text{Clay}_{\text{hydrometer}} + 5.294$ ,  $R^2=0.74^*$ ). Similar results also obtained for silt content (regression equation of  $\text{Silt}_{\text{pipette}} = 1.028\text{Silt}_{\text{rapid}} - 2.467$ ,  $R^2=0.68^*$  for pipette vs. Rapid method against for pipette vs. hydrometer method). Whereas, regression relationships between the results of Rapid and pipette methods for sand content indicated that the proposed Rapid method produced slightly different results and had lesser coefficients of determination ( $\text{Sand}_{\text{pipette}} = 0.897\text{Sand}_{\text{rapid}} - 2.236$ ,  $R^2=0.69^*$ ) than that of hydrometer method ( $\text{Sand}_{\text{pipette}} = 0.878\text{Sand}_{\text{hydrometer}} + 0.221$ ,  $R^2=0.075^{**}$ ) It should be pointed out that \* and \*\* in regression equations indicate that the  $R^2$  values are statistically significant at the probability level of 0.05 and 0.01, respectively.

The coefficient of determination ( $R^2$ ), slope and intercept of regression equations between the measured primary particles using the applied Rapid method and the standard method of pipette demonstrated that clay particles of entire soil samples measured by Rapid method were the most accurate among all of the measured soil particles. Whereas, the sand contents of entire soils measured by Rapid method were the least accurate measurements (Figure 1). In another word, similar to those obtained from the absolute differences between the measured primary particles, the lowest and the highest precision for the results of Rapid method were obtained for clay and sand particles, respectively.

### **Separated soil types**

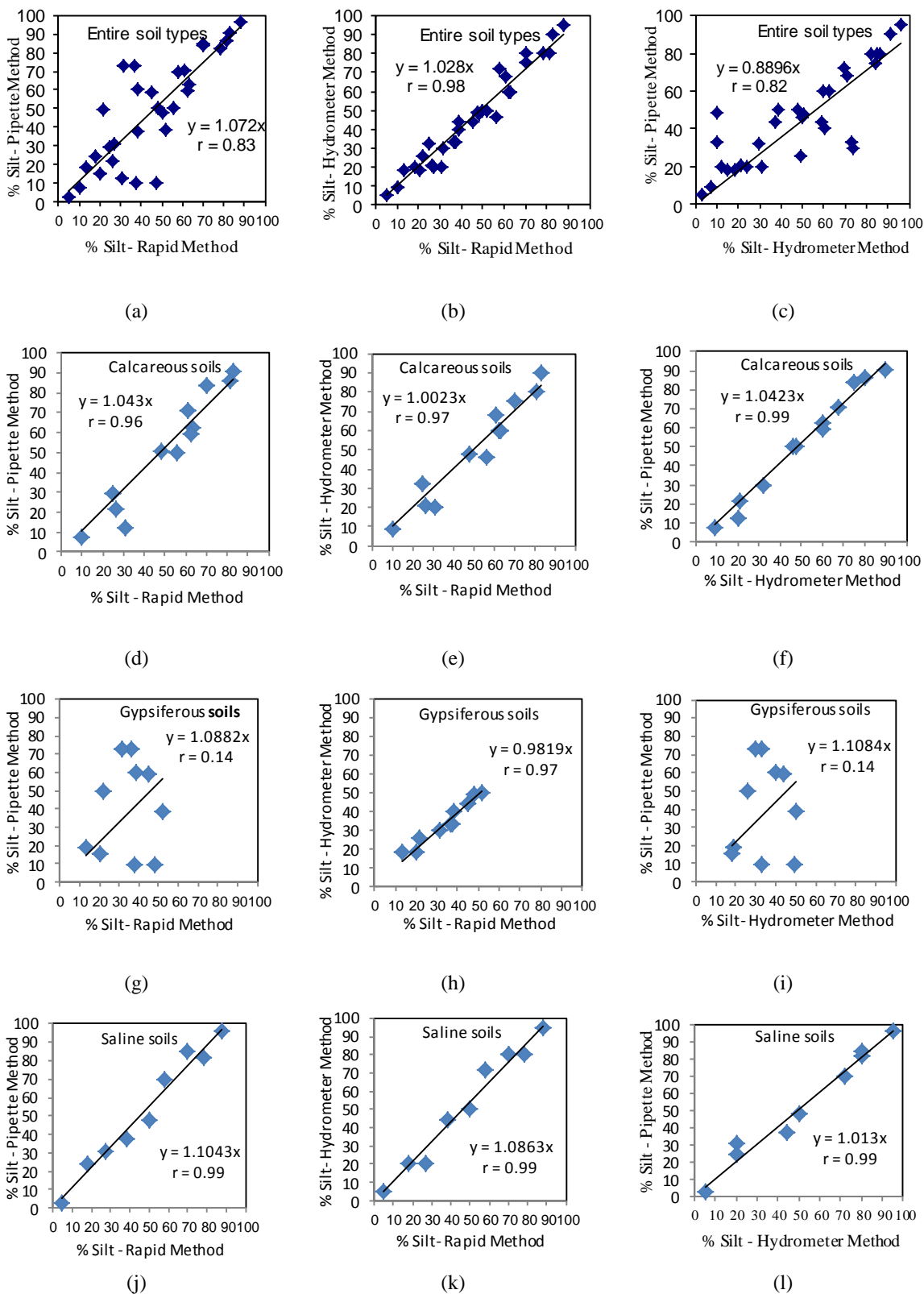
It should be noted that in the case of separated soil types for obtaining more accurate comparison the y-intercept term of regression relationships between the results of applied methods forced to zero. The forcing of y-intercept term to zero resulted in the negative and meaningless  $R^2$  in some cases especially for gypsiferous soils. Therefore,

the Pearson correlation coefficients ( $r$ ) were used instead of determination coefficients ( $R^2$ ). Linear regression analyses demonstrated a successful separation between the measured primary particles of studied soil types especially in the case of gypsiferous and non-gypsiferous (calcareous and saline) soils (Figures 2 to 4). In other words, for particle size comparisons the separation based on gypsum contents was very helpful. Zobeck (2004) also reported that separation of calcareous and non-calcareous soils was helpful in determination of soil primary particles using rapid laser diffraction in comparison to that of pipette method. He stated that some of carbonate in calcareous soils may break down during the sample preparation process and can result in different amount of primary particles using the mentioned applied methods. Furthermore, he reported that the lower coefficients of determination between the results of applied procedures are probably caused by the unpredictable nature of the breakdown of carbonate grains.

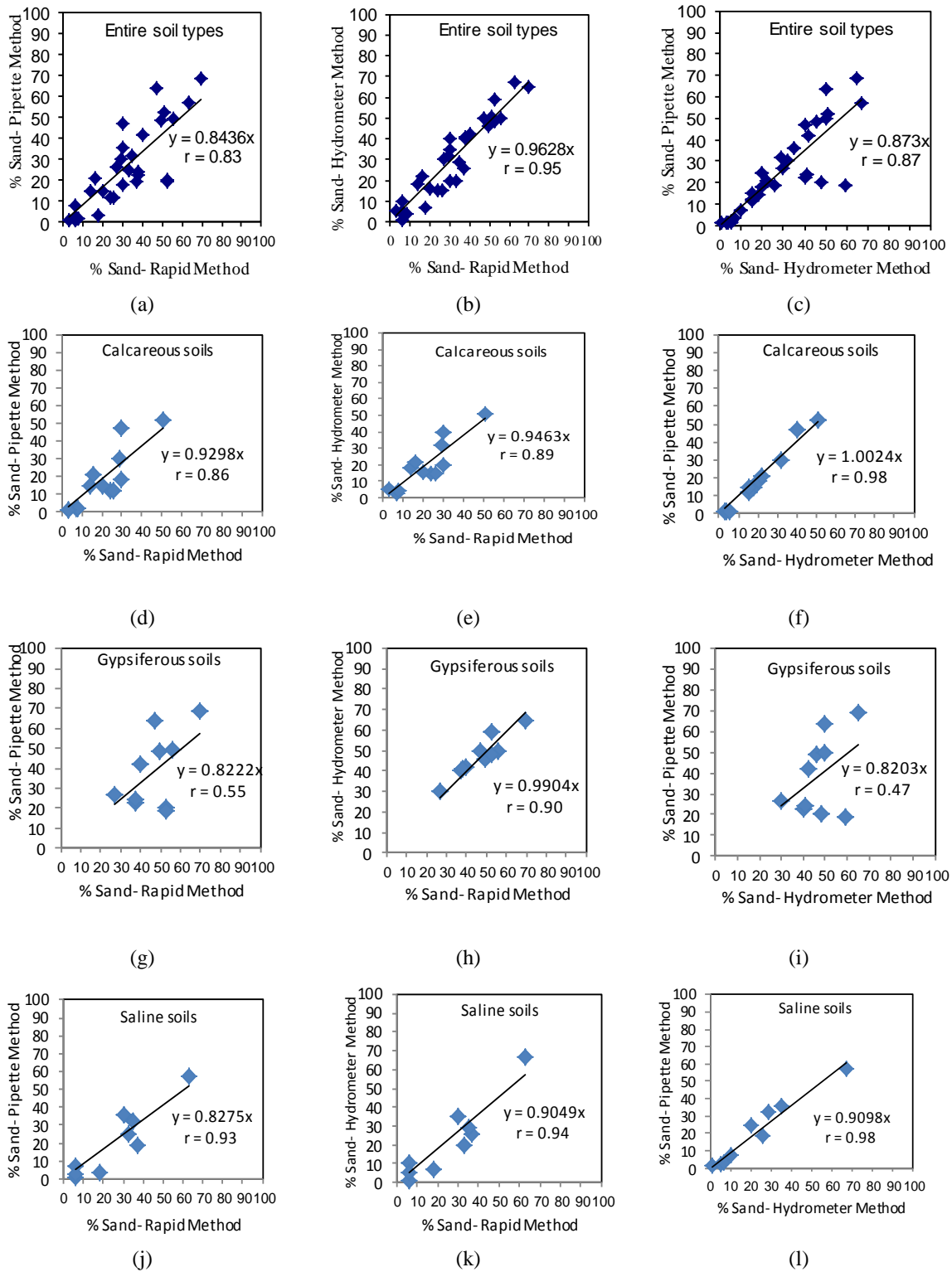
Results indicated that the lowest  $r$  values were observed for comparison between the results of measured particles using the Rapid or hydrometer methods vs. the standard method of pipette. The  $r$  values between measured clay contents using the Rapid and pipette methods for entire soils, calcareous, gypsiferous and saline soil types were 0.83, 0.92, 0.14 and 0.96, respectively; whereas, this coefficient was 0.83, 0.96, 0.14, and 0.99 for silt and was 0.83, 0.86, 0.55, and 0.93 for sand contents, respectively (Figures 2 to 4). The higher values of  $r$  between the measured clay contents for calcareous and saline soils and its lower values for gypsiferous soils in comparison to that of obtained for the entire soils confirm that the studied soils have been successfully separated into aforementioned soil types. In other words for all of measured primary particles, the following order of closeness between the Rapid and pipette methods was observed in studied soil types:

Saline soils > Calcareous soils > Entire soil types > Gypsiferous soils

In general the highest correlation coefficient ( $r$ ) and the closest slope to 1 for the regression equations between the results of Rapid and pipette methods were obtained in the studied saline soils; whereas, the lowest  $r$  and the most different slopes



**Figure 3** Regression relationships between the measured silt particles of studied soil types using different applied methods (the r values of <0.65 is statistically non-significant and r values of 0.65 to 0.9 and those of greater than 0.9 are statistically significant at the probability levels of 0.05 and 0.01, respectively).



**Figure 4** Regression relationships between the measured sand particles of studied soil types using different applied methods (the  $r$  values of  $<0.65$  is statistically non-significant and  $r$  values of  $0.65$  to  $0.9$  and those of greater than  $0.9$  are statistically significant at the probability levels of  $0.05$  and  $0.01$ , respectively).

to 1 were observed for gypsiferous soils (Figures 2 to 4). The findings indicate that application of Rapid method in comparison to pipette method result in the highest and the lowest accurate measurements of soil particles for saline and gypsiferous soils, respectively. Therefore, it can be concluded that in the case of saline (and somehow calcareous) soils the simple and fast Rapid method can be used instead of multistep and time-consuming method of pipette with the same precision. But the results of Rapid method were different with those of pipette for the primary particles of gypsiferous soils. Therefore, it is not recommended to use this simplified method for mechanical analysis of gypsiferous soils.

Calculated index of agreement (d) for every measured primary particle of each separated soil types were summarized in Table 2. Findings revealed that the mean index of agreement between the results of applied Rapid method and standard method of pipette over all of measured primary particles were 0.989, 0.982, 0.912, and 0.710 for saline, calcareous, entire, and gypsiferous soil types, respectively. The same results were obtained between the results of Rapid and hydrometer methods and also between the results of hydrometer and pipette methods. In general, application of this index of evaluation also confirmed the results of regression analysis for ranking the studied soil types based on the precision of measured soil particles using the applied Rapid method. Evaluation of the results using the index of agreement confirmed that the measured clay particles

of entire soils using the applied Rapid method were the most accurate among the other particles. While, the measured sand contents of entire soils using Rapid method were the least accurate ones i.e., the index of agreement were 0.959 and 0.887 for measured clay and sand particles of entire soil types, respectively (Table 2). In other words, similar to those obtained from the absolute comparisons and regression equations between the results of Rapid and pipette methods for the measured particles, the least and the most accurate results of Rapid method were obtained for clay and sand particles, respectively.

### Conclusions

Findings of this study demonstrated that clay particles of entire soil samples measured by Kettler (2001) proposed Rapid method were the most accurate among the measured soil particles. Whereas, sand content that measured by Rapid method was the least accurate measurement.

Results also revealed that the amount of sand content was overestimated with application of Rapid method as compared to that of pipette probably due to incomplete dispersion of soil particles in Rapid method which result in take some flocculated clay or silt particles into consideration as sand particles (coarser textures). Therefore, it can be concluded that using of the Rapid method may lead to more accurate results for mechanical analysis of finer textured soils than the coarser ones.

**Table 2** Values of calculated index of agreement (d) between the measured primary particles of studied soils using the simplified Rapid method of Kettler (2001) and the standard methods of pipette and hydrometer.

	Primary soil particles	Rapid vs. Pipette	Rapid vs. Hydrometer	Hydrometer vs. Pipette	Mean
Entire soils (mean = 0.925)	Clay	0.959	0.954	0.863	0.901
	Silt	0.890	0.984	0.910	0.928
	Sand	0.887	0.989	0.973	0.974
	Mean	0.912	0.976	0.915	
Calcareous soils (mean = 0.993)	Clay	0.974	0.979	0.997	0.983
	Silt	0.984	0.991	0.996	0.990
	Sand	0.988	0.993	0.999	0.993
	Mean	0.982	0.988	0.997	
Gypsiferous soils (mean = 0.650)	Clay	0.868	0.951	0.427	0.749
	Silt	0.456	0.985	0.433	0.625
	Sand	0.805	0.983	0.803	0.864
	Mean	0.710	0.973	0.555	
Saline soils (mean = 0.995)	Clay	0.992	0.995	0.998	0.995
	Silt	0.988	0.990	0.996	0.991
	Sand	0.986	0.991	0.997	0.991
	Mean	0.989	0.992	0.997	

Furthermore, findings revealed that application of Rapid method resulted in the most and the least accurate measured soil particles in saline and gypsiferous soils in comparison to that of pipette method, respectively.

Results of regression analysis showed that Rapid and pipette methods worked slightly different for determining all of soil particle classes; whereas, the results of Rapid and hydrometer methods was statistically similar. Therefore, in common applications in which there is no need to great amount of precision, the Kettler (2001) proposed Rapid method can be used instead of time-consuming method of hydrometer.

Rapid method resulted in relatively more accurate clay and silt contents than hydrometer method. Whereas, applying hydrometer procedure resulted in the more accurate measurements for the sand contents. Regression analysis also revealed that for all of measured primary particles, the following order of closeness between the Rapid and pipette methods was observed in studied soil types: Saline soils > Calcareous soils > Entire soil types > Gypsiferous soils. In other words, the findings indicate that application of Rapid method in comparison to pipette method result in the highest and the lowest accurate measurements of soil particles for saline and gypsiferous soils, respectively. Therefore, it can be concluded that in the case of saline and calcareous soils the simple and fast Rapid method can be used instead of multistep and time-consuming method of pipette with the same precision. But since in the case of gypsiferous soils the results of Rapid method were different with those of pipette, therefore, it is not recommended using this simplified method for mechanical analysis of gypsiferous soils.

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### References

- Abtahi, A., N. Karimian and M. Solhi. 1992. Semi Detailed Soil Science Report of Badjgah- Fars Province. Project Report No. 66-AG-420-216, Department of Soil Science, College of Agriculture, Shiraz University, Shiraz, Iran.
- Cambardella, C.A. and E.T. Elliott. 1992. Particulate soil organic matter changes across a grassland cultivation sequence. *Soil Sci. Soc. Am. J.* 56: 777-783.
- Cambardella, C.A., A.M. Gajda, J.W. Doran, B.J. Wienhold and T.A. Kettler. 2001. Estimation of particulate and total organic matter by weight loss-on-ignition. In R. Lal, J.M. Kimble, R.F. Follett and B.A. Stewart, eds. *Assessment Methods for Soil Carbon*. CRC Press, Boca Raton, Florida, USA.
- Doran, J.W. and A. J. Jones. 1996. *Methods for Assessing Soil Quality*. SSSA Spec. Publ. 49. SSSA, Madison, Wisconsin, USA.
- Gee, G.W. and J.W. Bauder. 1986. Particle-size analysis. In A. Klute, ed. *Methods of Soil Analysis, Part 1*, 2<sup>nd</sup> ed. Agron. Monogr. 9. ASA and SSSA, Madison, Wisconsin, USA.
- Hashemi, S.S. 2010. Determination of Mineralogical and Micromorphological Properties of Gypsiferous Soils with Different Moisture Regimes of Fars Province. Ph.D. Thesis, Shiraz University, Shiraz, Iran.
- Hassink, J. 1994. Effects of soil texture and grassland management on soil organic C and N and rates of C and N mineralization. *Soil Biol. Biochem.* 26: 1221-1231.
- Hesse, P.R. 1976. Particle size distribution in gypsic soils. *Plant Soil* 44: 241-247.
- Jafari, S. 2005. Study of Changes in Structural, Physicochemical Potassium Fixation and Clay Mineralogy Transformation of Sugarcane, Rotational Cropping and Non-cultivated Soils (Khuzestan), Iran. Ph.D. Thesis, Shiraz University, Shiraz, Iran.
- Kettler, T.A, J.W. Doran and T.L. Gilbert. 2001. Simplified method for soil particle-size determination to accompany soil-quality analyses. *Soil Sci. Soc. Am. J.* 65: 849-852.
- Khormali, F. 2003. Mineralogy, Micromorphology and Development of the Soils in Arid and Semiarid Regions of Fars Province, Southern Iran. Ph.D. Thesis, Shiraz University, Shiraz, Iran.
- Khormouji, N. 2013. Physicochemical, morphological, and mineralogical characteristics of soils of Bushehr-Borazjan. M.Sc. thesis, Department of Soil Science, College of Agriculture, Shiraz University, Shiraz, Iran.
- Moosavi, A.A. and A.R. Sepaskhah. 2012. Artificial neural networks for predicting unsaturated soil hydraulic characteristics at different applied tensions. *Arch Agron. Soil Sci.* 58: 125-153.
- Ozturk, H.S. and I. Ozkan. 2002. Solute movement in large soil columns under different water flow velocities. *Die Bodenkultur.* 53: 182- 189.
- Porta, J. 1998. Methodologies for the analysis and characterization of gypsum in soils: A review. *Geoderma* 87: 31-46
- Rivers, D.E., C.T. Hallmark, L.T. West and R. Dress. 1982. A technique for rapid removal of gypsum from soil samples. *Soil Sci. Soc. Am. J.* 46: 1338-1340.
- Saxton, K.E. and W.J. Rawls. 2006. Soil water characteristic estimates by texture and organic matter for hydrologic solutions. *Soil Sci. Soc. Am. J.* 70: 1569-1578.

- Soil Survey Staff. 1999. Soil Survey Manual. Agric. Handbook No. 18. Washington, D.C., USDA–NRCS, U.S. Gov. Print. Office.
- Stern, R., N. Alperovitch and G.J. Levy. 1989. Rapid removal of gypsum by resin prior to particle size distribution analysis in soils. *Soil Sci.* 148: 448-451.
- Wakindiki, I.I.C. and M. Ben-Hur. 2002. Soil mineralogy and texture effects on crust micromorphology, infiltration, and erosion. *Soil Sci. Soc. Am. J.* 66: 897-905.
- Willmott, C.J. 1982. Some comments on the evaluation of model performance. *Bull. Am. Meteor. Soc.* 63: 1309-1313.
- Zobeck, T.M. 2004. Rapid soil particle size analysis using laser diffraction. *Appl. Eng. Agric.* 20: 633-639.

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