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Full Length Research Paper

Determination of Consistency Limits of Different Agricultural Soils

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Abstract

This study was an attempt to determine the consistency limits (shrinkage, plastic and liquid) of soil. The experiment was conducted in four different classes, namely loam, silty loam, silty clay loam and silty clay. The plastic and liquid limits obtained by the Casagrande's method were 22.10 and 26.30% for loam, 24.18 and 30.50% for silty loam, 25.01 and 38.50% for silty clay loam with 32.20 and 47.70% for silty clay soils, respectively. The drop cone-penetration plastic and liquid limits were 20.80 and 24.40% for loam, 22.00 and 27.40% for silty loam, 23.0 and 34.00% for silty clay loam, 28.10 and 42.80% for silty clay soils, respectively. The shrinkage limits for loam, silty loam, silty clay loam and silty clay soils were 16.52, 17.86, 20.39 and 24.76%, respectively. The test results reveal that the ratio of Casagrande's to drop cone-penetrometer methods gives approximately 1.1. It can be suggested that cone-penetrometer test results of consistency limits multiplied by a factor of 1.1 would give the values as obtained by Casagrande's method.

Key words: Agricultural soil, Plastic limit, Liquid limit, Consistency Limit, Casagrande's method and Shrinkage limit.

INTRODUCTION

Soil is a heterogeneous granular material comprising of a complicated matrix of solid granular particles with the air and water filling the voids in varying proportions(Kurtey and Reece, 1970). The main index properties of coarse-grained soils are the particle size and relative density, and for fine-grained soils are the Atterberg's limits or the soil consistencies. Consistency limits of Soils: Swedish Agricultural Engineer A. Atterberg in 1911 mentioned that a fine-grained soil could exist in four states, namely the liquid, plastic, semi-solid and solid states. The water content at which the soil changes from one state to the other state is known as consistency limits or Atterberg's limits. Shrinkage limit is defined as the maximum water content at which a reduction of water content will not cause a decrease in the volume of the soil mass. The soils at solid state possess water content in the shrinkage limit. The plasticity of a soil is its ability to undergo deformation without cracking of fracturing. A plastic soil can mould into various shapes when it is wet. The liquid limit is the water content at which the soil property changes from the liquid state to the plastic state.

The liquid and plastic limits are frequently used in both the agricultural and civil engineering soils for classifying the fine-grained soils and in the design and control tests of earthworks (Soane and Campbell, 1972). The addition of liquid and plastic limit values in testing gives a better indication of the mechanical behavior of soil in the field. The liquid and plastic limits determined by the traditional Casagrande's method are suitable particularly for clay soils and the method fails to produce accurate results for sandy soil. Black (1957) determines the routine plastic limit from the method developed by Casagrande in 1932 remains in little changed. This empirical method is subjective and suffers from poor

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reproducibility to such an extent that the test is unsuitable for control testing of earth works (Sherwood and Ryley, 1970). If we have knowledge of moisture content in soil, it is necessary for soil compaction control, in determining consistency limits of soils and for the calculation of the stability of all kinds of earth works and foundations.

In an attempt to overcome the deficiencies of Casagrande method, a new method commonly know the cone-penetration test (CPT) developed by Cambell (1976) has emerged for quick determination of liquid and plastic limits for the soils of wide varieties. The liquid limit is determined simply by carrying out of drop cone test over a suitable range of water content. The drop cone penetrometer method for liquid limit determination is more reproducible and easy to conduct than the Casagrande method and the test result relates to the soil behavior. The frequent use of cone penetrometer is to characterize the soil strength easily and rapidly. The cone index as penetration as penetration resistance provides the relative indications of soil strength conditions (Smith and Dumas, 1978). The cone test is widely used for assessment of compacting and loosening effects of agricultural machines (Soane and Cambell, 1972) and in tillage and off-road mobility research as an indicator of soil strength and density characteristics (Wells et al., 1981). The objectives of the present research work were to determine the liquid and plastic limits of four classes of soil by Casagrande's and drop cone penetration methods, to compare the results obtained by Casagrande's and drop cone penetration methods and to determine the shrinkage limits of soils.

METHODOLOGY

Collection of Soil

Soils were collected from eight selected locations - Agronomy Farm of BAU, OjanBareara, VatiBareara, Bhobokhali, Borbilla and Ghagra, Bhaluka and PhulpurUpazila of Mymensingh district. The soils at a depth of 30 cm were collected by digging and were carried to the laboratory. The collected soils were first dried naturally and then pulverized by hammering. The foreign matters and vegetation were removed through sieving by IS 425 μm sieve and the screened soils were used for different tests. The textural classifications were accomplished using the facilities available at Department of soil science, BAU Mymensingh. The details of the analysis are given in Table 1.

From these above soil samples, only four types of soil were taken for research work are given in Table 2.

Shrinkage limit

The conventional mercury method of measuring the shrinkage limit of soils was applied in this research work.

Apparatus Required

Evaporating dish, Porcelain (about 12 cm diameter with flat bottom), Spatula, Shrinkage Dish (Circular, porcelain or non-corroding metal dish-3 nos. having a flat bottom and 45 mm in diameter and 15 mm in height internally), Straight Edge Steel-15 cm in length, Glass plates (2 no. each mm one plate shall be of plain glass and the other shall have prongs), Sieves(2mm and 425-micron IS sieves), Oven, Graduate-Glass(having a capacity of 25 ml and graduated to 0.2 ml and 100 cc one mark flask), Balance-Sensitive to 0.01 g minimum, Mercury, Wash bottle containing distilled water, Cone penetrometer and Liquid limit device (Casagrande's) etc.

Preparation of soil paste

1. About 100 gm of soil sample was taken from a thoroughly mixed portion of the material passing through 425-micron I.S. sieve.
2. About 30 gm the above soil sample was placed in the evaporating dish and thoroughly mixed with distilled water and creamy paste was made. Water content used somewhere around the liquid limit.
3. The inside of the shrinkage dish was coated with a thin layer of Vaseline to prevent the soil sticking to the dish.
4. The dish was filled with three layers by placing approximately 1/3 rd of the amount of wet soil with the help of a spatula. The dish was tapped gently on a firm base until the soil flows over the edges and no apparent air bubbles exist. This process was repeated for 2nd and 3rd layers also till the dish is completely filled with the wet soil. The excess soil was stricken and made the top of the dish smooth. All the soil adhering to the outside of the dish was wiped off.
5. The weight of the dish with wet soil was taken immediately and recorded the weight.
6. The wet soil cake was air-dried for 6 to 8hrs until the color of the pat turns from dark to light. Then the soil cake was oven-dried to constant weight at 105^0C to 110^0C about 12 to16 hrs.
7. Remove the dried disk of the soil was removed from the oven and cooled in a desiccator. Then the weight of the dish with the dry sample was obtained.
8. The weight of the empty dish was determined and recorded.
9. The wet soil volume was equal to the inner volume of the shrinkage dish.

The inner volume of the shrinkage dish = $\pi r^2 h$
where,
r = inner radius of shrinkage dish in cm = 4.5/2 = 2.25 cm

Table 1. Textures and classification of sample soils

Sample soil	Sand (%)	Silt (%)	Clay (%)	Soil Types
Agronomy Farm	3.64	68	28.36	Silty loam
OjanBareara	19.64	74	6.36	Silty loam
VatiBareara	27.64	50	22.36	Silty loam
Bhobokhali	7.64	54	38.36	Silty clay loam
Borbilla	7.64	54	38.36	Silty clay loam
Ghagra	5.64	66	28.36	Silty clay loam
Bhaluka	9.64	42	48.36	Silty clay
Phulpur	39.64	42	18.36	loam

Table 2. Textures and classification of sample soils for research work

Sample soil	Sand (%)	Silt (%)	Clay (%)	Soil Types
Phulpur	39.64	42	18.36	loam
VatiBareara	27.64	50	22.36	Silty loam
Ghagra	5.64	66	28.36	Silty clay loam
Bhaluka	9.64	42	48.36	Silty clay

h =inner height of shrinkage dish=1.5 cm

Volume of shrinkage, Vs =

$$\frac{\text{Weight of Mercury}}{\text{Specific gravity of Mercury (13.6)}}$$

10. The volume of shrinkage dish was determined which is evidently equal to the volume of the wet soil as follows. The shrinkage dish with dried soil pat was placed in an evaporating dish and filled the dish with mercury till it overflows slightly. It was pressed with plain glass plate firmly on its top to remove excess mercury. Then, the weight of the shrinkage dish with dry soil pat was weighted. Thus the weight of mercury was found the weight of mercury divided by the specific gravity of mercury gives the volume of mercury, i.e. the shrinkage volume of the soil pat.

Volume of dry soil pat = volume of weight – shrinkage volume of soil pat

The equation for calculating shrinkage limit is given below

Shrinkage limit (w_s) = $\{w – (V-V_0) \times \gamma_w / W_0\} \times 100$

where, w = Moisture content of wet soil pat in decimal

V = Volume of wet soil pat in cm^3

V_0 = Volume of dry soil pat in cm^3

W_0 = Weight of oven dry soil pat in gm.

γ_w = Unit weight of water, gm/cm^3

Plastic Limit

Procedure

1. About 20 gm was thoroughly mixed and was taken as sample passing through 425 micron IS sieve.
2. It was mixed thoroughly with distilled water in the evaporating dish till the soil mass becomes plastic enough to be easily molded with fingers.
3. It was Allowed to season for sufficient time (for 24 hrs) to allow water to permeate throughout the soil mass
4. About 10gms of this plastic soil mass was taken and rolled it between fingers and glass plate with just sufficient pressure to roll the mass into a threaded of uniform diameter throughout its length. The rate of rolling shall be between 60 and 90 strokes per minute.
5. The rolling was continued till getting a threaded of 3 mm diameter.
6. The soil was needed together to a uniform mass and re-rolled.
7. The process was continued until the thread crumbles when the diameter is 3 mm.
8. The pieces of the crumbled thread were collected in air tight container for moisture content determination.
9. The test was repeated 3 times and take the average value of results were calculated to the nearest whole number.

Liquid limit

Procedure

1. About 120 gm of air-dried soil from a thoroughly mixed portion of material passing 425 micron I.S sieve was to be obtained.
2. Distilled water was mixed with the soil thus obtained in a mixing disc to form a uniform paste. The paste should have a consistency that would require 30 to 35 drops of the cup to cause closer of the standard groove for sufficient length.
3. A portion of the paste was placed in the cup of liquid

limit device and spread into portion with few strokes of a spatula.
4. It was trimmed to a depth of 1cm at the point of maximum thickness and returned the excess of soil to the dish.
5. The soil in the cup should be divided by the firm strokes of the grooving tool along the diameter through the centre line of the follower so that clean sharp groove of proper dimension is formed.
6. The cup was lifted and dropped by turning the crank at the rate of two revolutions per second until the two halves of soil cake come in contact with each other for a length of about 1 cm by flow only.
7. The number of blows required to cause the groove close to about 1 cm should be recorded.
8. A representative portion of soil was taken from the cup for water content determination.
9. The test was repeated with different moisture contents at least three more times for blows between 10 and 40.

Cone Penetrometer Method

Cone penetrometer consists of a stainless steel cone having an apex angle of $30^0 \pm 1^0$ and a length of 35 mm. The cone is fixed at the lower end of a sliding rod which is fitted with a disc at its top. The total mass of the cone, sliding rod and the disc is 80 gm+ 0.05 gm. The prepared soil paste is placed in a cup of 50 mm internal diameter and 50 mm height. The cup is placed below the cone and allows penetrating the soil for 30 seconds. The water content at which the penetration is 20 mm is the liquid limit. Since it is difficult to obtain the penetration of 20 mm exactly, liquid limit is determined from the equation given below

$$w_l = \frac{w_y}{0.77 \log y}$$

Where w_l = Liquid limit
y = penetration when water content is w_y
w_y = Water content when penetration y

Procedure

1. 500 gm of dried soil was taken in a glass plate and adding water for makes the paste.
2. The paste was kept for 30 minutes for maturing.
3. The cup of 50 mm internal diameter and 50 mm height with this paste was filled so that there is no entrapped air. The excess soil was removed and the cup surface was leveled.
4. The cup was placed below the cone penetrometer and lowered the cone gradually so as to just touch the surface of the soil in the cup.
5. The graduated scale was adjusted as zero when cone touch the cup surface.
6. The cone was released and allowed penetrating the soil for 30 seconds.
7. When the cone penetrates 20 mm exactly then soils sample was taken for water content determination.
8. It is very difficult to get exactly 20 mm penetration, so the penetration y near 20 mm for the water content w_y was measured the process repeated 10 times.
9. At last liquid limit was calculated by using the above equation.

RESULTS AND DISCUSSION

The plastic limits of the soils as determined by the Casagrande's methods and the test results are given in Table 3. From the table 3 the plastic limits of loam, silty-loam, silty-clay loam and silty-clay soils were found 22.10, 24.18, 25.01 and 32.2% respectively.

The liquid limits of the soils were determined by the Casagrande's methods. The liquid limit values were obtained from the number of blows vs. moisture content curve as shown in Figure 1. Referring to figure1 the liquid limits of loam, silty loam, silty-clay loam and silty clay were showed 26.30, 30.50, 38.50 and 47.70%, respectively.

Relationship between cone-penetration and moisture content

The plastic and liquid limits of the soils are determined by the cone-penetrometer method. The effect of moisture content (w), on cone-penetration (d), of a constant size and weight of cone were obtained for the soil of moisture content ranging from 7 to 50%. The plastic and liquid limits of the soils were obtained from the moisture content vs. cone penetration curve as shown in Figure2.

The figure showed that there exists of two water levels for the same penetration depth except a particular state of minimal penetration at a particular moisture level. The soil moisture corresponding to the minimal penetration of cone is the soil's plastic limit commonly called as the cone-penetration plastic limit (CPPL) of the soil. The liquid limits were taken as the soil moisture level corresponding to 20 mm penetration depth. Figure2 shows that the plastic limits of loam, silty loam, silty-clay loam, silty-clay soils were 20.8, 22.0, 23.0 and 28.1% respectively, and also the liquid limits of these soils were 24.4, 27.4, 34.0 and 42.8% respectively.

Comparison between the Casagrande and Cone-penetration Methods

The Casagrande's technique is the widely practiced method of finding the consistency limits of clay soils

Table 3. Comparison between Casagrande's and cone-penetration methods

Soil type	Plastic limit,%			Liquid limit,%		
	Method		Casagrande/ cone penetration	Method		Casagrande /cone penetration
	Casagrande	Cone-penetration		Casagrande	Cone-penetration	
Loam	22.10	20.80	1.063	26.30	24.40	1.078
Silty-loam	24.18	22.00	1.100	30.50	27.4	1.113
Silty-Clay-loam	25.01	23.00	1.087	38.50	34.0	1.132
Silty-Clay	32.20	28.10	1.146	47.70	42.8	1.115

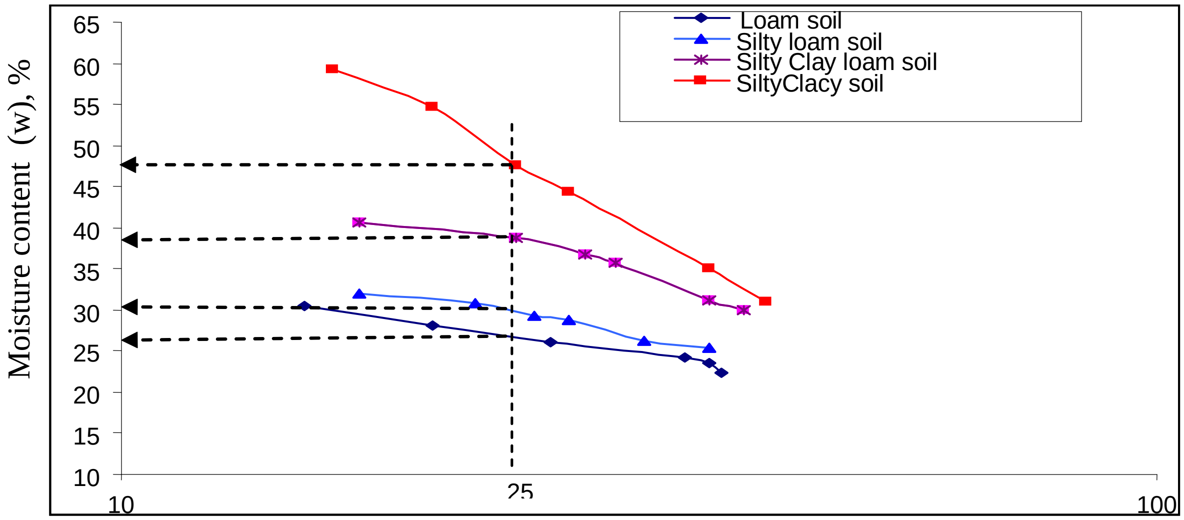

Figure 1. Liquid limits of soil by Casagrande's method

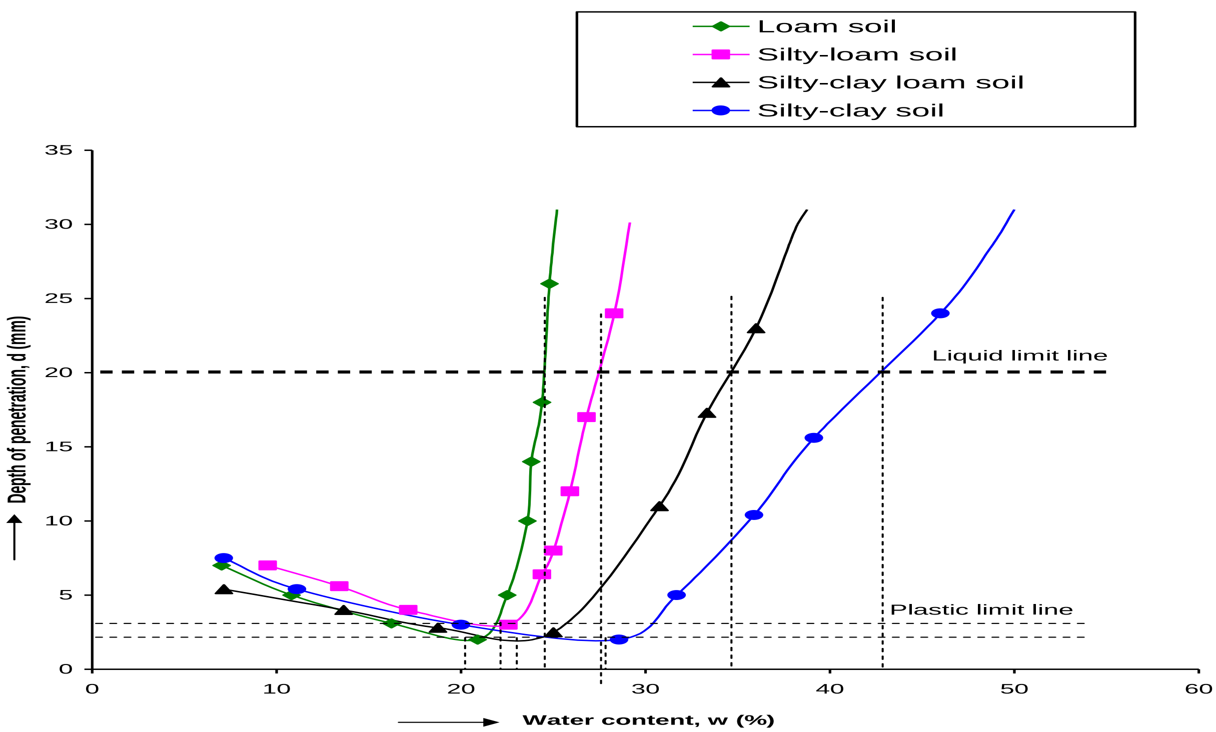

Figure 2. Effect of water content on cone penetration for different types of soil

Table 4. Plastic limit (PL), Liquid limit (LL) and Plasticity index (PI) of soil samples

Methods	Soil Sample	Liquid limit LL (%)	Plastic limit PL (%)	Plasticity index, PI (%)
Casagrande's	Loam	26.30	22.10	4.20
	Silty-loam	30.50	24.18	6.32
	Silty-Clay-loam	38.50	25.01	13.49
	Silty-Clay	47.70	32.20	15.50
Cone penetration	Loam	24.40	20.80	3.60
	Silty-loam	27.40	22.00	5.40
	Silty-Clay-loam	34.00	23.00	11.00
	Silty-Clay	42.80	28.10	14.70

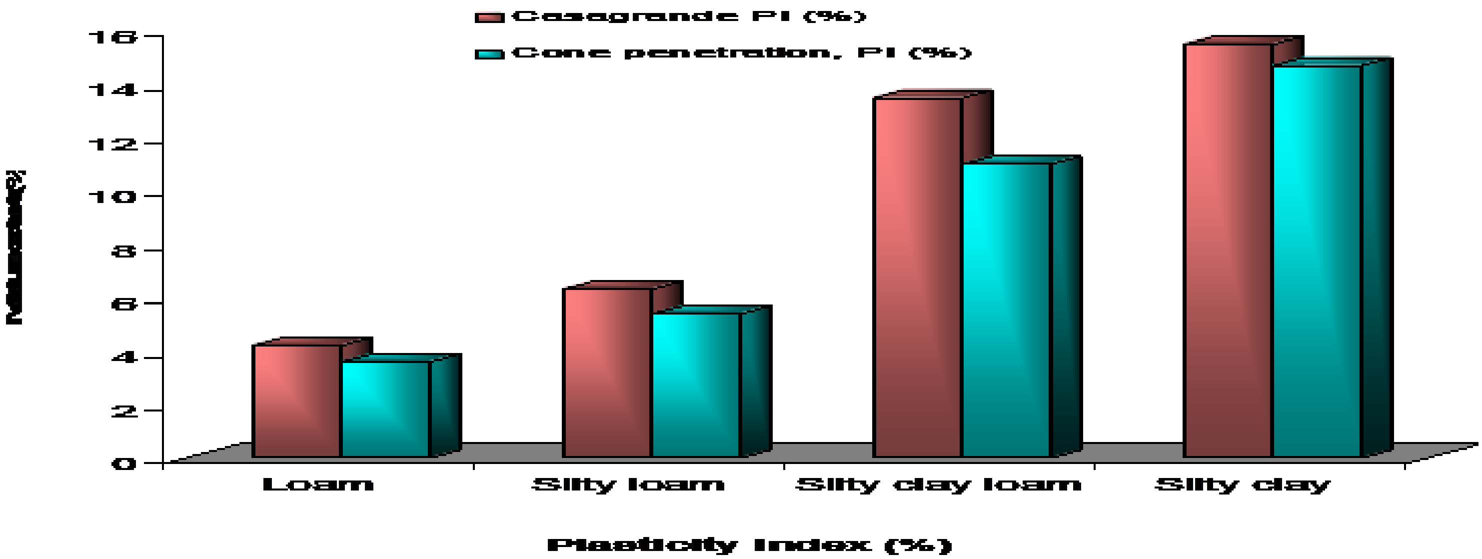

Figure 3. Plasticity index of different soil samples

Table 5. Shrinkage, Plastic and Liquid limits of sample soils by different methods

Soil type	Shrinkage limit, SL (%)	Plastic limit, PL (%)		Liquid limit, LL (%)	
		Casagrande	Drop cone penetration	Casagrande	Drop cone penetration
Loam	16.52	22.10	20.80	26.30	24.4
Silty loam	17.86	24.18	22.00	30.50	27.4
Silty clay loam	20.39	25.01	23.00	38.50	34.0
Silty clay	24.76	32.2	28.10	47.70	42.8

while the cone penetration method is being practiced since a few decades back. The conventional Casagrande method is unable to measure the consistencies of sandy soil, in which fields; the cone penetration method is highly effective. The consistency limits of four different soils obtained experimentally by the casagrande and the cone-penetration methods are given in Table 3.

Referring to table 3 the casagrande method always produces higher values of consistency limits than those of the cone penetration method and the ratio of Casagrande to drop cone-penetration methods gives approximately 1.1.

From the Table 4 it was found that the plasticity index of Casagrande's method was greater than the plasticity index of cone-penetration method. Plasticity index of different soil samples is shown in Figure 3.

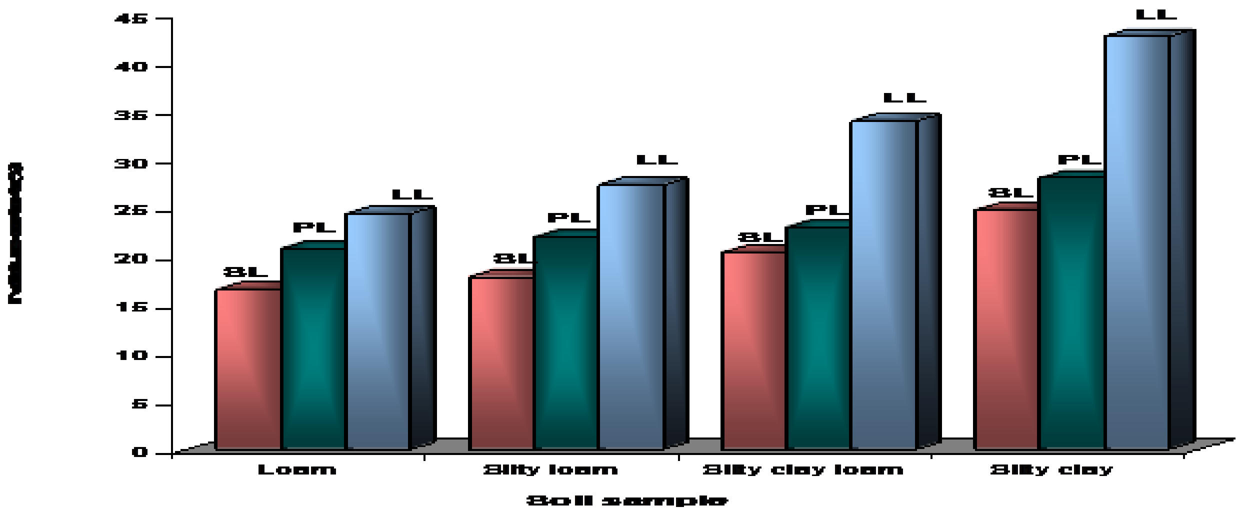

Figure 4. Shrinkage, Plastic and Liquid limits of sample soils

The shrinkage limits of the soils determined by the mercury method and the limit values were obtained from the Table 4. The shrinkage limits of loam, silty loam, silty-clay loam and silty clay were 16.52, 17.86, 20.39 and 24.76% respectively. The results of shrinkage, liquid and plastic limits of sample soils are shown in Table 5 (Plastic and liquid limit results from cone penetration method)

CONCLUSION

The plastic and liquid limits obtained by the Casagrande's method were greater than the values obtained by the drop cone-penetrometer method. The consistency limits of soil were increased with the clay content in the soil. The test results reveal that the ratio of Casagrande's method to drop cone-penetrometer gives approximately 1.1. It can be suggested that cone-penetrometer test results of consistency limits multiplied by a factor of 1.1 would give the values as obtained by Casagrande's method.

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