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Immediate and long-term effects of lime and wheat straw on consistency characteristics of clayey soil

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Abstract. Clayey soils with swelling and shrinkage characteristics have been major causes for many problems in roads, buildings and other civil engineering infrastructure in various areas of Pakistan, particularly where there are several patches of such soils on either side of Indus River. As the consistency characteristics are directly related with the variation of moisture content; therefore, this study was explicitly focused to investigate the effect of lime and wheat straw on the consistency characteristics of clayey soils with relatively high swelling and shrinkage characteristics. The consistency test results indicate that by the increase in lime content there is a decrease in the plasticity index of soil; for instance, 10% lime content resulted to 59% decrease in the plasticity index value. On the other hand; the addition of wheat straw resulted in a significant increase in the plasticity index; for instance, 10% wheat straw content resulted to a 120% increase in the plasticity index. This study has further shown that the shrinkage and swelling of clayey soils which resulting to several problems in the civil engineering infrastructures may adequately be managed through mixing an appropriate amount of lime and wheat straw as soil stabilizing agent for both immediate and long-term effects.

Keywords: consistency; wheat straw; lime; clayey soil; shrinkage

1. Introduction

The topography of River Indus delta mainly consists flat terrain and there are several patches of clayey soils (Giosan *et al.* 2006). On either side of river Indus in Pakistan significant variation in the groundwater table (GWT) is noticed during various seasons (Qureshi *et al.* 2008). Usually, an increase in the groundwater table in the monsoon season is noticed. These variations in GWT results to change in the moisture content of the existing soil, which is mainly consisted of clayey patches. As the consistency characteristics are directly related with moisture; therefore, these characteristics would give a direct measure of soil mechanical behaviour and represent an integration of soil properties and this can be used to estimate properties such as compressibility of soil (Moreno-Maroto and Alonso-Azcárate 2015). Usually, the clayey and silty soils exhibit low to high plasticity; therefore, the control and monitoring of the consistency characteristics of these soils have a significant role in the soil-structure interaction problems. The clayey soils are supposed to be more sensitive to moisture content; for instance, clayey soils may be hard as a rock when dry and may be soft just like flowing fluid when highly moist. Thus the behaviour of clayey soils changes from a solid state to liquid state as a function of moisture content. Similarly, the clayey soils exhibit shrinkage and shrinkage cracks due to the loss of moisture and swells due to the gain of moisture, ultimately resulting to various engineering problems. Therefore, it is necessary to stabilize clayey soils against shrinkage and swelling for eliminating or marginalizing the subsequent damages to corresponding structures constructed on such soils. Prior to any construction appropriate ground improvement is usually carried out. For ground improvement the common soil stabilizing agents are usually cement; lime, fly ash, straws, etc.

Lime found to be used frequently in the treatment of clayey soils (Al-Mukhtar *et al.* 2012, Bell 1996, Bourokba Mrabent *et al.* 2017, Greaves 1996, Yong and Ouhadi 2007). Natural and artificial fibres are also used for ground improvement. Natural fibres are supposed to be biodegradable (Blackburn 2005, Zhang *et al.* 2005), although degradability may the concern while using natural fibres for soil improvement; however, several researchers used natural fibres for the stabilization of soil (Ali 2011, Chebbi *et al.* 2017, Gaw and Zamora 2011, Güllü and Khudir 2014, Lekha *et al.* 2015, Millogo *et al.* 2014, Ramesh *et al.* 2010, Sharma *et al.* 2015, Sivakumar Babu *et al.* 2008, Vishnudas *et al.* 2006).

Another aspect of the use of natural fibre is found in the remediation of shrinkage cracks. Since century's natural fibres such as wheat straw, rice husk, cow dung etc. have been used to avoid shrinkage cracks in the mud structures. Wheat straw is used particularly in controlling the shrinkage cracks (Zong *et al.* 2014). According to Siva Kumar Babu, *et al.* 2008 (Babu *et al.* 2008) the use of coir which is a biodegradable material in the expansive black cotton soil can result in improved engineering behaviour of the soil. Natural fibres (straw) control the 'plastic' behaviour and influence the breaking way of the adobe samples i.e.,

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improvement in the stability of adobe houses (Quagliarini and Lenci 2010). The cow dung is applied to mud plaster which is partially dry to help stop the development of cracks; however, earlier publications suggest that cow-dung may improve workability and durability (Ashurst and Ashurst 1988).

Random studies have been conducted in the past addressing the consistency and shrinkage characteristics of soils in various parts of the World. For this purpose various types of soil stabilizing agents were used by different researchers; for example, lime (Cai *et al.* 2006, Dash and Hussain 2015, Gringarten *et al.* 1975, Siddique and Hossain 2011), cement (Bayat *et al.* 2013, Gharib *et al.* 2012a, b, Kalantari *et al.* 2010), wheat straw (Ashour and Wu, 2010), rice husk (Okafor and Okonkwo 2009, Rao *et al.* 2012, Rathan Raj *et al.* 2016), fly ash (Dixit *et al.* 2016, Kalyanshetti and Thalange 2013, Sharp 1993, Witherspoon *et al.* 1980) and polypropylene additives (Cai *et al.* 2006, Soğancı 2015) etc. Effect of various soil stabilizing agents were also investigated on the liquid limit, plastic limit and plasticity index; such as lime (Basma and Tuncer 1991, Bayat *et al.* 2013, Choobbasti *et al.* 2010, Ji-ru and Xing 2002, Sherwood 1993, Siddique and Hossain 2011), cement (Basha *et al.* 2005, Sherwood 1993, Yetimoglu and Salbas 2003), rice husk (Basha *et al.* 2005, Choobbasti *et al.* 2010), fly ash (Ji-ru and Xing 2002), and additives (Naranagowda *et al.* 2016); whereas, wheat straw was found to be a good source for shrinkage cracks reduction (Ashour *et al.* 2010, Ashour and Wu, 2010, Bouasker *et al.* 2014, El Sharif *et al.* 2013). However, no significant literature is available addressing the indigenous issues arising in the clayey soil zones present either side of Indus River Delta in Pakistan which resulted to serious challenges in the infrastructure development in the region; For example the construction of roads, bridges, residential and commercial buildings etc. To address these challenges to stabilize the soils against swelling and shrinkage, local materials such as lime and wheat straws which are available in abundance in this region were taken into consideration.

In this study, it has been explicitly focused to investigate the effect of lime and wheat straw on the consistency characteristics of the clayey soils for short term and long term stability analysis. For this purpose a series of tests were conducted using various percentages of lime and wheat straw considering the immediate/short-term effects; a second series of the tests were conducted as a function of time/long-term effects and the results of both series of the tests were compared and analysed.

2. Materials and methods

The low plastic clayey soil was used as base materials, whereas lime and wheat straw (WS) were used as soil stabilizing agents. Sieve analysis, hydrometer and consistency limits tests were conducted for the classification of soil. According to the USCS classification the soil may be classified as silty clays (ML-CL). The base material soil consisted of silt-49%, clay-38%, colloids-10%, and sand-3%. As in Table 1, summarizes the physical properties of clayey soil while Fig. 1 represents the gradation of a clayey soil. Fig. 2 represents the soil composition studied in this manuscript.

Table 1 Physical properties of clayey soil

Description	Value
Percent Passing No. 10	99.2
Percent Passing No. 40	98.2
Percent Passing No. 200	96.5
Liquid limit (LL)	23.85
Plastic limit (PL)	16.08
Plasticity Index, (PI)	7.77
Shrinkage limit(SL)	13.14
Specific Gravity	2.600
USCS Classification	CL-ML
Sand between 4.75mm to 0.075mm	3.45%
Silt size, 0.074 to 0.002 mm	48.88%
Clay size, 0.002-0.005 mm	37.98%
Colloids, smaller than 0.005 mm	9.70%
Maximum dry density (KN/m^3)	18.02
Optimum moisture content (%)	16.0

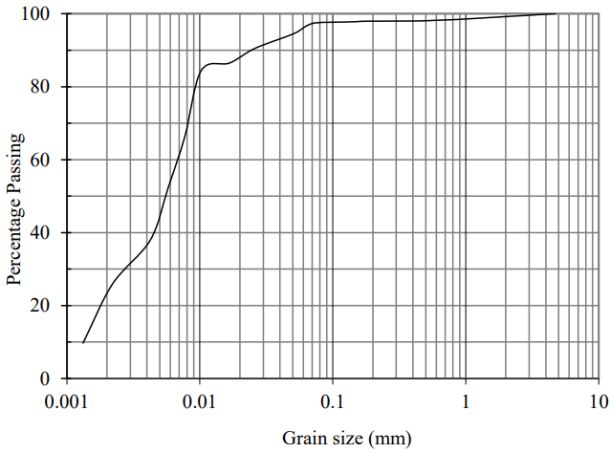


Fig. 1 Grain size distribution of clayey soil used in the study

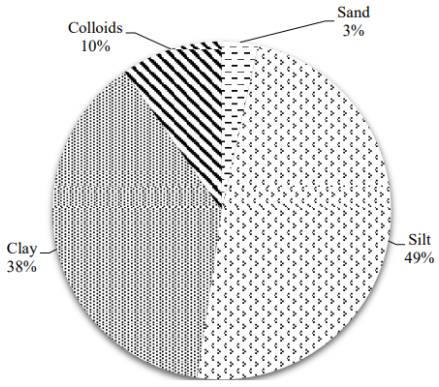


Fig. 2 Composition of soil

2.1 Wheat straw

Threshed wheat straws were used for reinforcement,

Table 2 Physical and Mechanical properties of wheat straw

Average diameter (D)	3.1 mm
Average length (L)	18.4 mm
Specific gravity (Gs)	0.34-0.38
Water absorption ratio (WAR)	300% (After 24 h)
Maximum tensile strength	10.133 MPa (1470 psi)

(a) Wheat straw

(b) Wheat straw threshing

(c) Threshed wheat straw

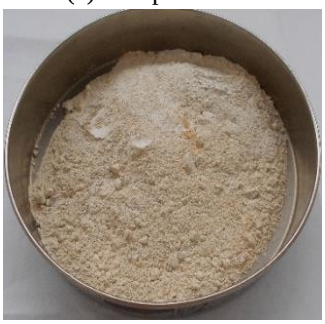
Fig. 3 Wheat straw at various stages

which is commonly available after separating the wheat from the straw using thresher machines as shown in Fig. 3. Physical and mechanical properties of wheat straw are given in Table 2.

2.2 Lime

Powdered lime is obtained after crushing lumps of limestone as shown in Fig. 4. The chemical composition of the lime studied in this manuscript is being presented in Table 3.

(a) Lumps of lime



(b) Powdered lime

(c) Sieving of lime

(d) Fine powdered lime

Fig. 4 Lime at various stages from (a)-(d)

Table 3 The chemical composition of lime

Constituent	Quantity
Insoluble in hydrochloric acid	0.03%
Substitutes not precipitate by NH_4-OX(a SO4)	2.5
Chloride	50 mg/kg
Sulfate	500 mg/kg
Cu	5 mg/kg
Fe	500 mg/kg
Pb	2 mg/kg
Zn	5 mg/kg
$CaCO_3$	3%

(a) Liquid limit test setup

(b) Plastic limit test setup

(c) Shrinkage limit test setup

Fig. 5 Consistency experimental setups

3. Experimental setups

For the consistency characteristics, Casagrande's liquid limit device, Plastic Limit Apparatus, Shrinkage limit Apparatus respectively as shown in Fig. 5.

4. Sample preparation

Samples were prepared using clayey soil as a base material. The representative samples were oven dried and sieved through 425-µm (No. 40) sieve. Material passing No. 40 sieve was taken for consistency limits tests. The base materials were then mixed with the required Percentage (%) of lime and wheat straw and were mixed thoroughly through dry mixing as shown in Fig. 6. The threshed wheat straws were mixed in random orientation into the soil. After dry mixing water was added and adjusted to reach to the various states of soil for achieving the consistency limits. The tests were performed as per ASTM standards (Standard 2000). The shrinkage limit tests were performed as per ASTM standards (ASTM D427-04). A paste of soil samples

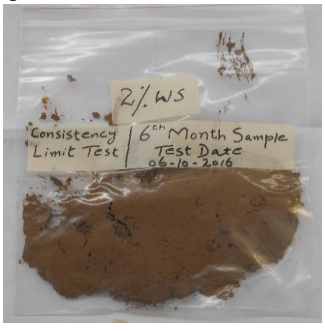
(a) Clay lumps in the stock

(b) Lime mixed with Soil

(c) Wheat straw mixed with Soil

Fig. 6 Wheat straw/lime mixed with soil in dry condition

(a) A paste of soil with 6% lime content



(b) A paste of soil with 2% wheat straw content

Fig. 7 Soil sample prepared for the function of time testing

added with 6% lime and 2% wheat straw prepared at optimum moisture contents 22% and 17% respectively. Samples were stored in moisture controlled plastic bags (as shown in Fig. 7) for the required period of time prior to the testing for consistency and shrinkage characteristics.

5. Testing procedure

In the first phase, the basic index properties of soil including moisture content, unit weight and specific gravity were determined. Following that, more ceremonial investigations had started that essentially includes the consistency limits of soil using different percentages of stabilizing agents (Wheat Straw and Lime) to determine the change in behaviour and interaction with soil. The consistency limits were determined as per ASTM D 4138. The Shrinkage Limit tests were performed as per the respective standards (ASTM D427). After the calculation of fundamental properties, the consistency and Shrinkage parameters were determined using different proportions of stabilizing agents and their interaction with soil. As the addition of natural fibres wheat straw and lime develops a composite material and therefore, the index properties of the base material would also get changed; therefore, in order to see the effect of the addition of the stabilizing agents; it is important to have the controlled parameters of the composite materials, such as unit weight, specific gravity, void ratio, etc. In the present study, while investigating the effect of soil stabilizing agents the controlled parameters were given due consideration and kept unchanged wherever required.

6. Results and discussion

Wheat straw is found to be a lightweight material with high water absorption which is evident from its specific gravity and water absorption ratio respectively. The water absorption coefficient is an important parameter in the mix of clay and fibres. In fact, it is to be known that the proportion of water absorbed by the straw deducing the amount of water that reacts with the binder (cement or lime matrix). Therefore, an additional amount of water may be required to add into the mixed composite for completing the hydration reaction.

6.1 Effect of wheat straw and lime on average specific gravity

While preparing the composite materials, the specific gravity of each ingredient may not be the same; therefore, for the specific gravity of the composite materials, the weightage average of the specific gravity may be used. The average specific gravity was determined by applying Eq. (1).

$$G_{av} = \frac{100 - L - F}{100} \times G_{soil} + \frac{L}{100} \times G_{Lime} + \frac{F}{100} \times G_{Fibre} \quad (1)$$

where; L is the lime content and F is the fibre content both taken in percentage.

Table 4 The average specific gravity of soil added with different percentages of wheat straw (WS) and Lime

% content	G_{soil}	G_{ws}	G_{lime}	G_{av} with WS content	G_{av} with Lime content
0	2.60	0.34	3.3	2.60	2.60
2	2.60	0.34	3.3	2.56	2.61
4	2.60	0.34	3.3	2.51	2.63
6	2.60	0.34	3.3	2.47	2.64
8	2.60	0.34	3.3	2.42	2.66
10	2.60	0.34	3.3	2.38	2.67

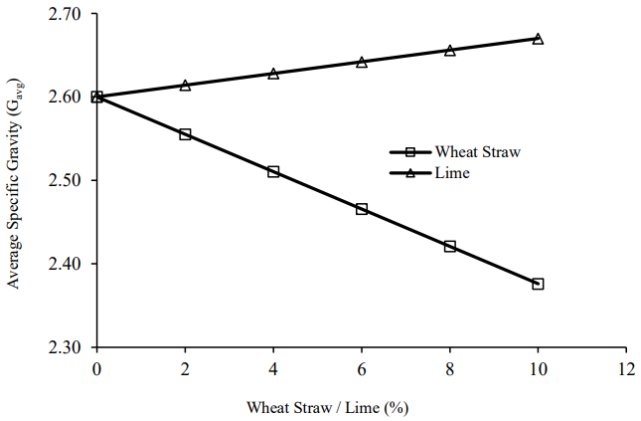


Fig. 8 Effect of percentage of lime and wheat straw on the G_{avg} of soil

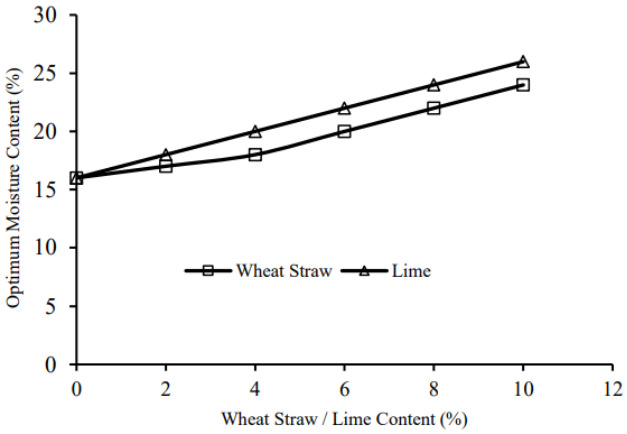


Fig. 9 Effect of lime and wheat straw on the optimum moisture content of the soil

The average specific gravity of clayey soil was found to be 2.60 and that of the wheat straw as 0.34, and that of lime is 3.3. The average specific gravity based on the percentage of wheat straw and lime is given in Table 4. The effect of percentage addition of wheat straw and lime is shown in Fig. 8 from the figure it can be seen that there is a gradual decrease in the average specific gravity of the composite material due to the increase in the wheat straw content and a gradual increase due to the increase in the lime contents. This could be because of the relatively low specific gravity of wheat straw and high specific gravity of lime which is 0.34 and 3.3 respectively as compared that of soil which is 2.60. Previous studies also reported a decrease in the

specific gravity due to the addition of relatively lightweight materials; such as the specific gravity of black cotton soil decreased with the addition of polypropylene fibre reported by Naranagowda *et al.* (2016).

6.2 Effect of wheat straw and lime on optimum moisture content

The results of the effect of lime and wheat straw on the optimum moisture content (OMC) are shown in Fig. 9 from the figure it can be seen that there is a gradual increase in the OMC due to the increase in the percentage of lime and wheat straw. The increase in the optimum moisture content may be due to the high absorption of wheat straw which found to be 300% and also due to the consumption of water in the heat of hydration of lime which has the specific heat of hydration of 0.29 Btu/lb at 100° F. Similar results about lime were also reported in the literature by Kavak and Akyarlı (2007), Rahman (1986), al-Swaidani *et al.* (2016), Choobbasti *et al.* (2010), Alhassan (2008), and Harichane *et al.* (2011). However, there is no relevant literature found regarding the effect of Wheat Straw (WS) content on the OMC.

6.3 Effect of wheat Straw on the consistency limits

The results obtained with the addition of wheat straw in soil with various percentages are summarized in Table 5. The effect of wheat straw content on the consistency limits is shown in Fig. 10 from the figure it can be seen that the rate of increase in consistency limits is high, up to 2% of fibre content. After 2% of fibre content the rate of increase is comparatively low for liquid limits and plastic limits, however, the plasticity index showing no significant change after 2% of the wheat straw content. Effect of wheat straw on the consistency characteristics have not yet been reported in the literature; however, the effect of cement, lime and rice husks ash were reported. For instance, according to Basha *et al.* (2005) the liquid limit and plastic limits were increasing with increasing the percentages of cement and rice husk ash with the combination of residual soil, but it has been noticed that the plasticity index is going to decrease.

6.4 Effect of lime on consistency limits

The results obtained with the addition of lime in soil with various percentages are summarized in Table 6. The effect of lime content on the consistency limits is shown in Fig. 11 from the figure it can be seen that the rate of increase in consistency limits is high, up to 2% of the lime content. After 2% of lime content the rate of increase of consistency characteristics is comparatively low for liquid and plastic limits; however, there is a decrease in the plasticity index of the soil. Similar results were reported by al-Swaidani *et al.* (2016), Kavak and Akyarlı (2007) and Harichane *et al.* (2011). The shrinkage limit is going to increase by the addition of lime up to 8% of the addition of lime content, then it goes to decrease.so it shows that the optimum lime content (OLC) is 8% in shrinkage limit test in low plasticity clayey soil mixed with lime. By findings of (Dash and Hussain 2015) the value of shrinkage limit

Table 5 Effect of wheat straw on the consistency limits

WS (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Shrinkage Limit (%)
0	23.85	16.08	7.77	13.14
1	36.1	22.98	13.12	21.21
2	41.3	24.44	16.86	22.13
4	42.79	25.87	16.92	24.03
6	45.3	27.81	17.49	25.69
8	46.72	29.35	17.37	27.32
10	47.5	30.33	17.17	28.11

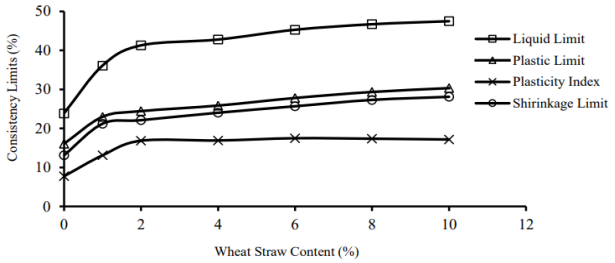


Fig. 10 Effect of wheat straw on liquid limit, plastic limit, plasticity index and shrinkage limit of soil

Table 6 Effect of Lime on the consistency limits

Lime Content (%)	Liquid limit LL (%)	Plastic Limit PL (%)	Plasticity Index PI (%)	Shrinkage Limits SL (%)
0	23.85	16.08	7.77	13.14
1	34.48	26.50	7.98	24.35
2	35.1	30.68	4.42	24.51
4	36.34	31.22	5.12	25.71
6	38.2	32.4	5.8	28.42
8	37.61	34.37	3.24	32.79
10	36.34	33.13	3.21	31.2

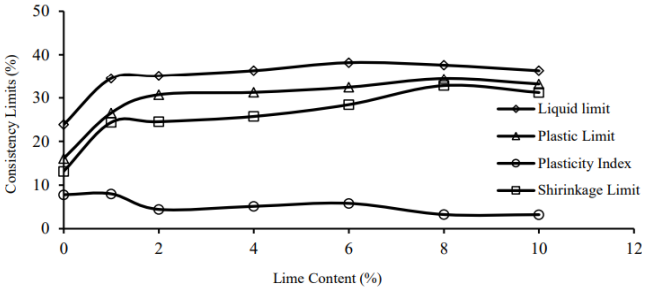


Fig. 11 Effect of lime on consistency characteristics

increased speedily until the 5% of lime then the proportion of increased trend has reduced at less curing of the time period.

7. Comparison of the effect of lime with wheat straw on the soil properties

7.1 Effect on liquid limit

The comparative analysis of lime with wheat straw on

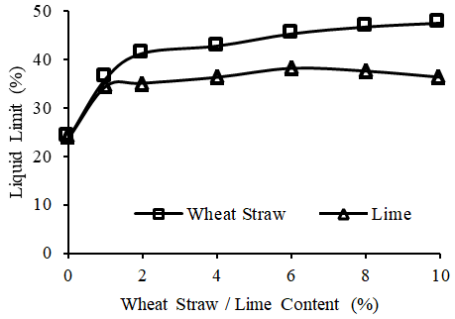


Fig. 12 Effect of wheat straw and lime on liquid limit

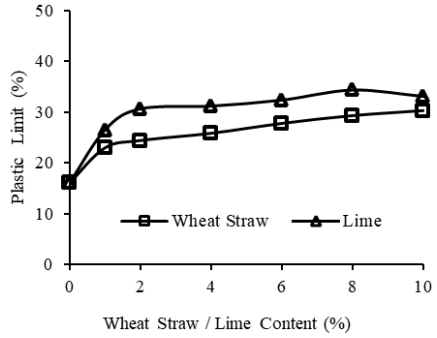


Fig. 13 Effect of wheat straw and lime on plastic limit

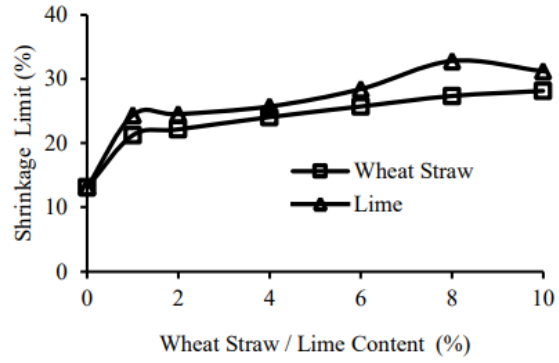


Fig. 14 Effect of wheat straw and lime on shrinkage limit

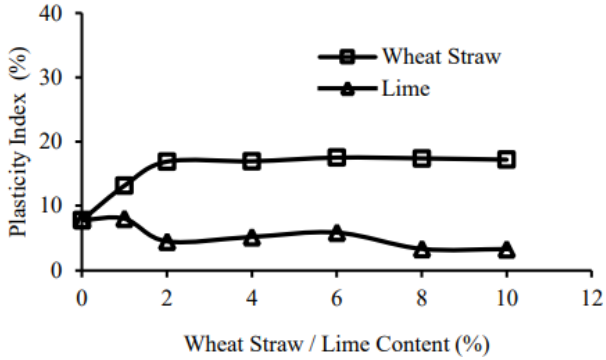


Fig. 15 Effect of wheat straw and lime on plasticity index

the liquid limit is shown in Fig. 12. From the figure it can be seen that up to 2% there is an increase in the liquid limit of the soil due to the addition of both lime and wheat straw, however, beyond 2% there is a slight gradual increase and slight gradual decrease in the liquid limit of the soil due to the addition of wheat straw and lime respectively. This could be due to the initial consumption of water due to absorption and hydration by wheat straw and lime respectively. Further increase in liquid limit due to wheat straw content might be because of the fibrous nature of the material and a slight decrease in the liquid limit may be due to the loss of frictional characteristics of lime. Previous studies by Bayat *et al.* (2013) have also reported more or less similar trends of the lime effect on the liquid limit of a clayey soil.

7.2 Effect on the plastic limit

The effect of lime and wheat straw on the plastic limit of a clayey soil is shown in Fig. 13. From the figure it can be seen that with the addition of lime and wheat straw in the soil there is a gradual increase in the plastic limit of the soil. Previous studies by Bayat *et al.* (2013) have also reported more or less similar trends of the effect of lime on the plastic limit.

7.3 Effect on shrinkage limit

The shrinkage limit tests were conducted by adding 0 to 10% of lime and wheat straw. The experimental observations of the effect of lime and wheat straw on the shrinkage limit are given in Fig. 14. From the figure it can be seen that there is a gradual increase in the shrinkage limit due to the increase in the wheat straw and lime contents. The increase in the shrinkage limit intern suggests that there is a decrease in the linear and volumetric shrinkage of the soil; a similar behaviour was also reported by Siddique and Hossain (2011).

7.4 Effect on plasticity index

The effect of lime and wheat straw on the plasticity index of soil is shown in Fig. 15 from the figure it can be seen that the addition of wheat straw resulting to increase in the plasticity index up to 2%, thereafter there is very slight increasing trend change in the values of plasticity index of soil. On the other hand, the addition of lime into soil results to decrease in the plasticity index of the soil, which in turn suggests that the addition of fibrous materials results to the increase in the plasticity and lime resulting to the decrease in the plasticity characteristics. Similar behaviour of clayey soils was also reported by Bayat *et al.* (2013).

7.5 Effect on linear shrinkage

The effect of lime and wheat straw on the linear shrinkage of clayey soil was determined through a series of tests conducted using various percentages of lime and wheat straw ranging from 0% to 10%. The results are tabulated as given in Table 7 and graphically represented as shown in Fig. 16. From the figure, it can be seen that there is a slight decrease in the linear shrinkage due to the increase in the lime and wheat straw content. This decrease in the linear shrinkage due to lime could be because of a decrease in the plasticity of the clayey soil whereas in case of wheat straw this could be due to the capturing of shrinkage cracks. Similar behaviour was also reported by Siddique and

Hossain (2011) about the effect of lime on linear shrinkage.

Table 7 Effect of reinforcement on linear shrinkage, volumetric shrinkage and shrinkage ratio

Reinforcement (%)	Effect of Lime on Linear Shrinkage (%)	Effect of Lime on Volumetric Shrinkage (%)	Effect of Lime on Shrinkage Ratio (%)	Effect of WS on Linear Shrinkage (%)	Effect of WS on Volumetric Shrinkage (%)	Effect of WS on Shrinkage Ratio (%)
0	4.93	34.71	1.96	4.93	34.71	1.96
2	2.69	20.21	1.59	3.63	23.35	1.59
4	2.29	19.23	1.58	3.41	21.39	1.50
6	2.39	16.48	1.53	3.30	20.60	1.34
8	2.19	13.15	1.42	3.20	14.72	1.24
10	1.63	12.17	1.43	2.63	16.31	1.16

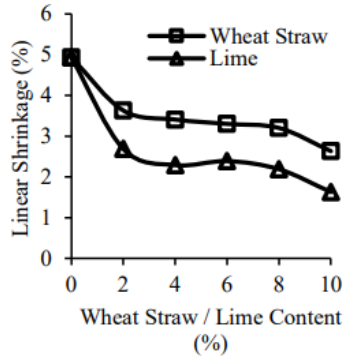


Fig. 16 Effect of addition of wheat straw and lime on linear shrinkage

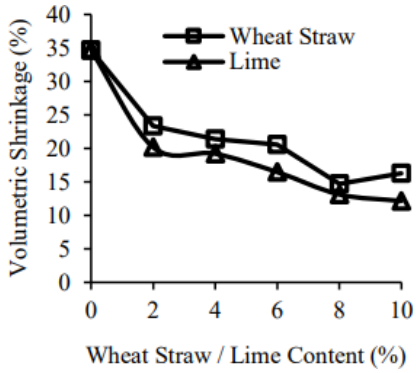


Fig. 17 Effect of addition of wheat straw and lime on volumetric shrinkage

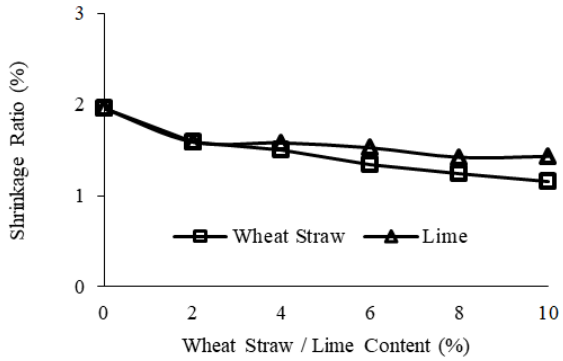


Fig. 18 Effect of addition of wheat straw and lime on shrinkage ratio

7.6 Effect on volumetric shrinkage

The effect of lime and wheat straw on the volumetric shrinkage of clayey soil was determined through a series of tests conducted using various percentages of lime and wheat straw ranging from 0% to 10%. The results are tabulated as given in Table 7 and graphically represented as shown in Fig. 17 from the figure it can be seen that the volumetric shrinkage of a clayey soil is decreasing with adding the percentages of lime and wheat straw content. The similar behaviour has been reported by Siddique and Hossain (2011).

7.7 Effect on shrinkage ratio

The effect of lime and wheat straw on the Shrinkage ratio of clayey soil was determined through a series of tests conducted using various percentages of lime and wheat straw ranging from 0% to 10%. The results are tabulated as given in Table 7 and graphically represented as shown in Fig. 18 from the figure it can be seen that the shrinkage ratio of a clayey soil is decreasing with adding the percentages of lime and wheat straw content. The similar behaviour has been reported by Siddique and Hossain (2011).

7.8 Effect on shrinkage cracks

The effect of lime, cement and wheat straw were investigated on the drying cracks sometimes also known as desiccating cracks. Clayey soil samples were taken and mixed with 6% lime, 6% cement, 2% wheat straw and with 6% lime + 2% wheat straw. The ranges of shrinkage were compared with a clayey soil sample as reference. All the samples were prepared at workable paste adding moisture equivalent to the plastic limit. The trays of samples were left for air drying at room temperature for 24 hours and thereafter sun-dried for further 72 hours (three days). The effect of soil stabilizing agents on shrinkage cracks is shown in Fig. 19 from the figure it can be seen that the effect of different soil stabilizing agents is varying from each other. The effect of lime, cement and wheat straw resulted in a decrease in the overall shrinkage of soil, however, the number of cracks and the direction of propagation is quite interesting. For example wheat straw resulted in capturing the length of shrinkage cracks only (Fig. 19(b)), addition of lime resulted in a more number of cracks as compared to clayey soil only (Fig. 19(c)), addition of cement resulted to reasonable decrease in the length and number of visible cracks only (Fig. 19(d)) and the combined lime and wheat straw resulted in a complete capture of drying cracks only (Fig. 19(e)).

7.9 The combined effect of lime and wheat straw

The combined effect of lime and wheat straw was also investigated by mixing 2% wheat straw and 6% lime by dry weight of clayey soil. The selection criteria of 2%WS and 6% lime content with the base material is based on the optimum performance of lime and wheat straw as soil stabilizing agents against the compressive strength of soil.

(a) Clayey soil

(b) Soil+2% WS

(c) Soil+6% lime

(d) Soil + 6% Cement

(e) Soil + 2%WS + 6% lime

Fig. 19 Effect of soil stabilizing agents on shrinkage cracks

The effect of lime, wheat straw and combined lime and wheat straw on the linear shrinkage of a clayey soil is given in Fig. 20 from the bar chart (as shown in Fig. 20) it may be seen that there is a decrease in the linear shrinkage of clayey soils as a function of wheat straw and lime.

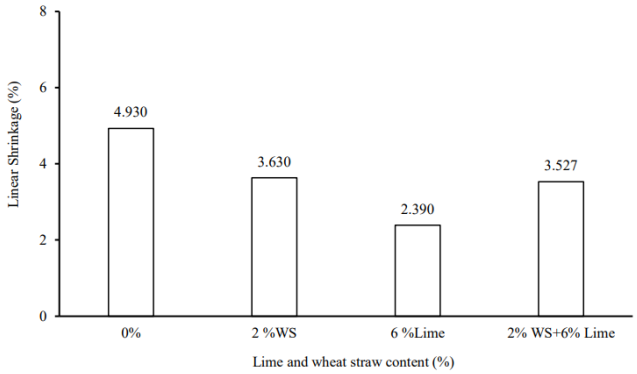


Fig. 20 Effect of lime and wheat straw on linear shrinkage at specific percentages of WS and Lime

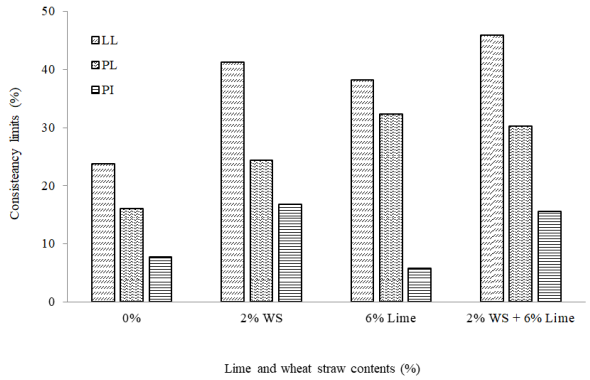


Fig. 21 Effect of wheat straw and lime on consistency limits at specific percentages of WS and Lime

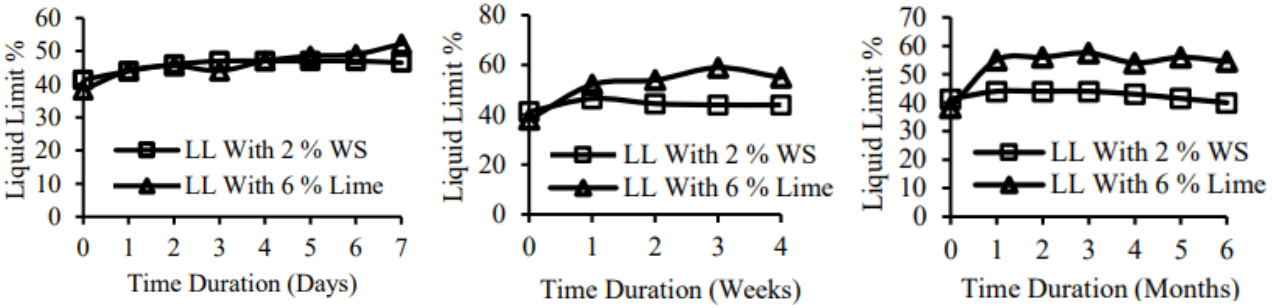
The effect of lime, wheat straw and the combined effect of lime and wheat straw on consistency limits of clayey soil are given in Fig. 21. From the bar chart (as shown in Fig. 20) it may be seen that there is an increase in the PI value of clayey soils as a function of wheat straw and a decrease in the PI value of clayey soil as a function of lime. However, the impact of combined effect is relatively greater than that of the clayey soil only. The reason may be the dominant effect of wheat straw which resulted to an increase in the PI value by 117% approx.

7.10 Time-dependent effect of lime and wheat straw

The effect of lime and wheat straw as a function of time may not be the same as that of the immediate results obtained from the fresh mix. There may be several reasons such as the reaction of lime with soil minerals and the decomposition of wheat straw in the soil mass. Therefore, a series of the tests were conducted as a function of time in order to investigate the effect of soaking period on the consistency characteristics.

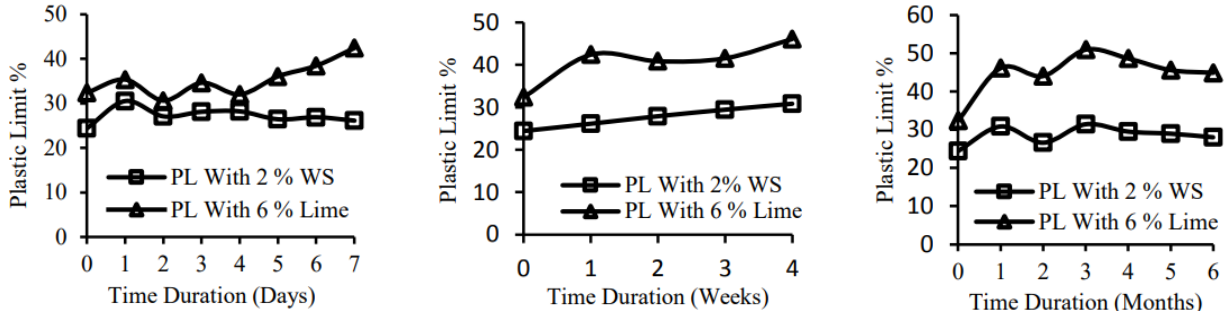
7.10.1 Effect of lime & wheat straw on Liquid Limit as a function of time

The effect of lime and wheat straw on the liquid limit as a function of time was determined and analyzed. For this



(a) Time duration in days (b) Time duration in weeks (c) Time duration in months

Fig. 22 Effect of lime & wheat straw on the liquid limit of soil as a function of time



(a) Time duration in days (b) Time duration in weeks (c) Time duration in months

Fig. 23 Effect of lime & wheat straw on the plastic limit of soil as a function of time

purpose, the testing was performed for the duration of days, weeks and months. The test results are shown in Fig. 22. From the figure it can be seen that the liquid limit with 6% of lime at the start days it is slightly increasing but after the passage of time duration it gave the stagnant result. The liquid limit is decreased with the addition of lime after the passage of specific curing time (Achampong *et al.*, 2013). By (Tuncer and Basma 1991) also stated that there is no significant effect of curing time on the reduction of liquid limit. The liquid limit with 2% wheat straw (WS) has increased the value up to the duration of the third week after this duration the value of liquid limit has slightly decreased and adopted stagnant trend up to the six months of duration. There is no proper literature is available which shows the wheat straw effect on the liquid limit after the passage of time. This was attributed to the fact that lime is an active admixture which initiated several reactions with the clay soils almost as soon as they were mixed.

7.10.2 Effect of lime & wheat straw on the plastic limit as a function of time

The effect of lime and wheat straw on the plastic limit as a function of time was determined and analyzed. For the purpose, the testing was performed for the duration of days, weeks and months. The test results are shown in Fig. 23 from the figure it can easily understand that the plastic limit is increasing with 6% lime sample after the passage of curing time. The initial value of plastic limit at zero-day curing was 35.5% which jumps to 50.92% at ninety days of curing. By (Achampong *et al.* 2013) found that a significant increase in plastic limits on the Low plasticity clay (CL) with the addition of lime content after the passage of curing time. The value of plastic limit with the addition of 2% WS is going to decrease with the passing of time.

7.10.3 Effect of lime & wheat straw on the plasticity Index as a function of time

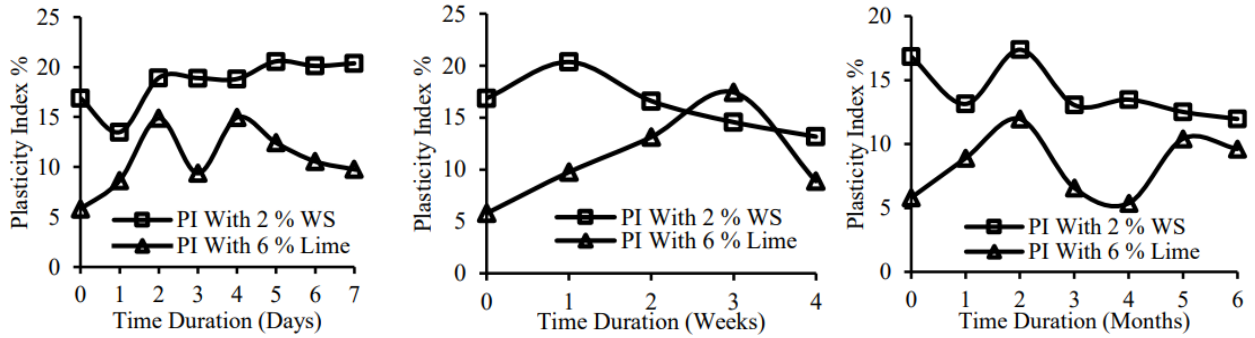
The effect of lime and wheat straw on the plasticity index (PI) of clayey soil was analysed for the duration of days, weeks and months. The results of the entire duration of six months are shown in Fig. 24. From the figure it can easily say that the plasticity index of the soil with 6 % lime is not showing any proper trend of the curve at the starting point the value is going to increase than at the middle stage its show decrease pattern then it goes increase and at last show increase pattern again. By Achampong *et al.* (2013) has observed that the curing time has no significant effect on the on plasticity index (PI) of a clayey soil. The value of plasticity index with 2% WS is going to increase up to seven days of curing after this the plasticity index is going to decrease.

7.10.4 Effect of lime & wheat straw on shrinkage limit as a function of time

The effect of lime and wheat straw on the shrinkage limit as a function of time was determined and analyzed. For this purpose, a series of tests were performed for the duration of days, weeks and months. The test results are shown in Fig. 25. From the figure it may be seen that with the addition of 6% lime the shrinkage limit is increased by the increase in the soaking period. Dash and Hussain (2015) also reported similar behaviour.

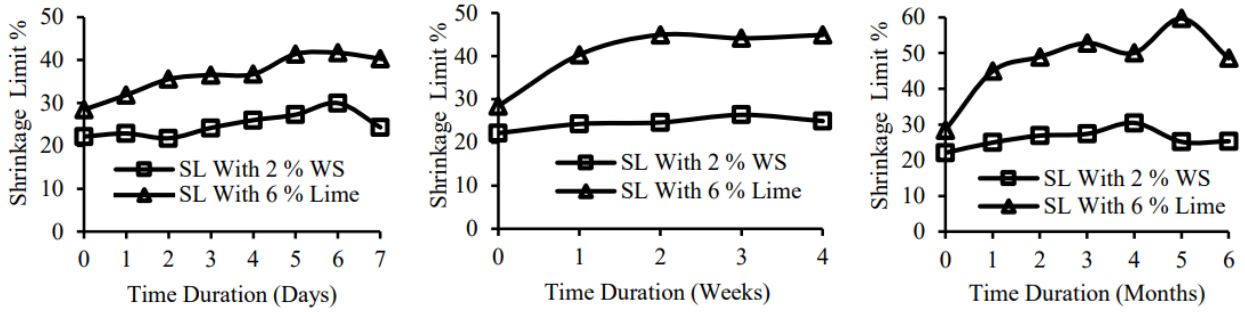
7.10.5 Effect of lime & wheat straw on Volumetric Shrinkage as a function of time

The effect of lime and wheat straw on the volumetric shrinkage as a function of time was determined and



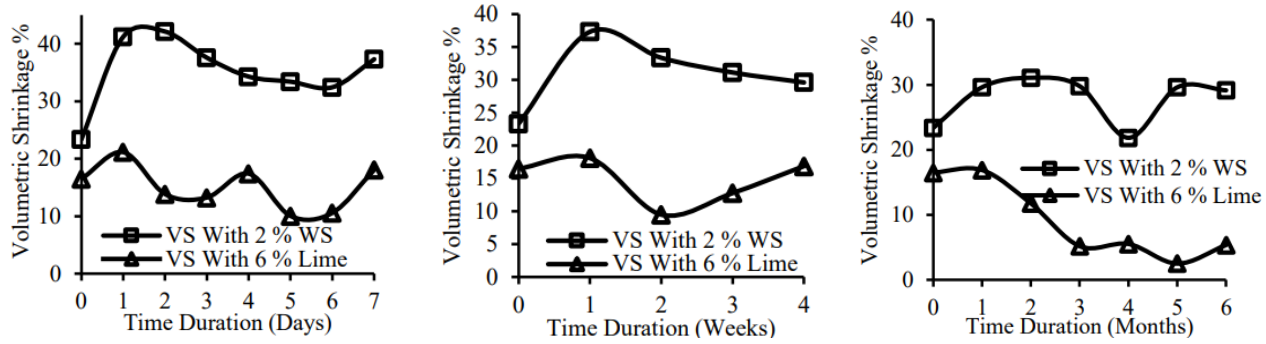
(a) Time duration in days (b) Time duration in weeks (c) Time duration in months

Fig. 24 Effect of lime and wheat straw on the plasticity index as the function of time



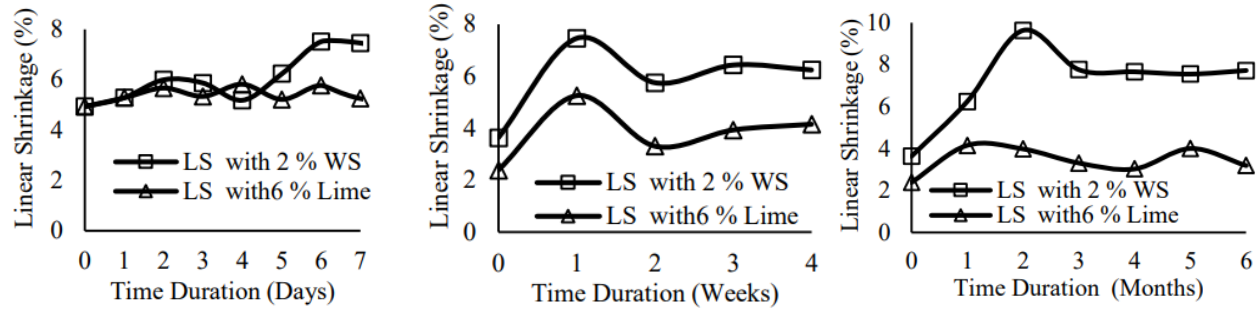
(a) Time duration in days (b) Time duration in weeks (c) Time duration in months

Fig. 25 Effect of lime and wheat straw on the shrinkage limit as the function of time



(a) Time duration in days (b) Time duration in weeks (c) Time duration in months

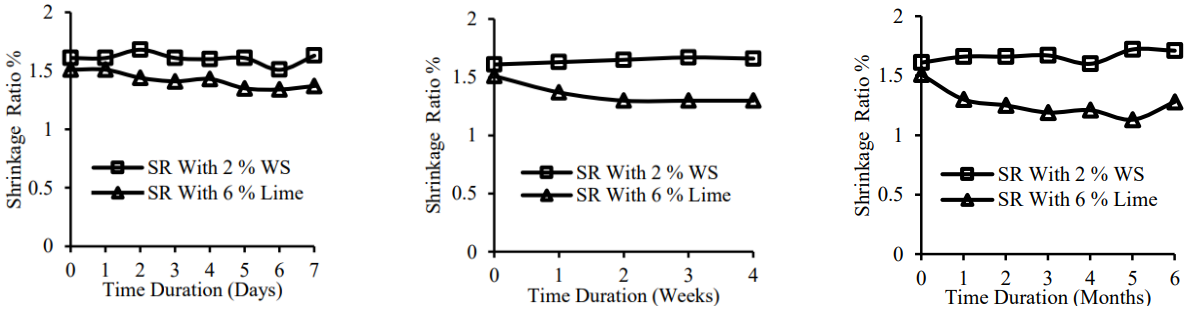
Fig. 26 Effect of lime and wheat straw on the volumetric shrinkage as the function of time



(a) Time duration in days (b) Time duration in weeks (c) Time duration in months

Fig. 27 Effect of lime and wheat straw on the linear shrinkage as the function of time

analyzed. For this purpose, a series of tests were performed for the duration of days, weeks and months. The test results are shown in Fig. 26. From the figure it can be seen that the volumetric shrinkage is decreasing with the passage of time for clayey soil sample added with 2% WS and 6% lime. Similar results were also reported for lime content by



(a) Time duration in days (b) Time duration in weeks (c) Time duration in months

Fig. 28 Effect of lime and wheat straw on the Shrinkage ratio as the function of time

Siddique and Hossain (2011).

7.10.6 Effect of lime & wheat straw on linear shrinkage as a function of time

The effect of lime and wheat straw on the linear shrinkage as a function of time was determined and analyzed. For the purpose, a series of tests were performed for the duration of days, weeks and months. The test results are shown in Fig. 27. From the figures it can be seen that the linear shrinkage is increasing up to 7 days of curing, however, thereafter there is fluctuation in the results and somehow the values may seem to be unchanged. This could be because that the loss of moisture is getting completed during a week period.

7.10.7 Effect of lime & wheat straw on shrinkage ratio with a function of time

The effect of lime and wheat straw on the shrinkage ratio as a function of time was determined and analyzed. For this purpose, a series of tests were performed for the duration of days, weeks and months. The test results are shown in Fig. 28. From the figures, it may be seen that the values of shrinkage ratio with 2% WS samples are not showing any significant effect with curing period. The samples with 6% lime content indicate that shrinkage ratio is decreasing as curing time is increasing. Similar results were also reported by Siddique and Hossain (2011).

8. Summary

Clayey soils with swelling and shrinkage characteristics have been major causes for many problems in roads, railways, buildings and other civil engineering infrastructure in various areas of Pakistan, particularly on either side of Indus River, where there are several patches of such soils. This study was focused to investigate the effect of lime and wheat straw on such types of soils. For this purpose, the effects of lime and wheat straw were investigated and analyzed through consistency characteristics which are an indirect measure of the swelling and shrinkage of soil. The swelling and shrinkage of the soil were measured directly and indirectly through, plasticity index, linear shrinkage, volumetric shrinkage, shrinkage ratio and shrinkage cracks, etc. From the experimental results and review of the existing literature, it may be summarized that:

1. The addition of lime and wheat straw ultimately resulting to decrease in the average specific gravity of the composite material, which could be because that both lime and wheat straw having a specific gravity less than that of the base material.
2. There is a gradual increase in the Optimum Moisture Content (OMC) due to the increase in the content of lime and wheat straw which might be due to the additional absorption of water by these agents (i.e., lime and wheat straw).
3. The addition of wheat straw resulted in an increase in plasticity index up to 2% of wheat straw content by about 117% approx.; however, a further increase in the WS content resulted in no significant change in the plasticity index of the soil for freshly mixed samples. The addition of 2% wheat straw as a function of time indicates fluctuation in the PI-values; nevertheless, for initial one-week results indicates an increasing trend and thereafter slight decreasing trend in the PI values.
4. The addition of lime resulted to slightly increase the plasticity index up to 1% of lime content increase 2.7% then decrease in plasticity index continuously as a result of an increase in the lime content in the freshly mixed samples. The addition of 6% lime as a function of time indicates that up to 21 days the plasticity index is going to increase after that it shows fluctuation in the PI-values and therefore, no specific trend can be decided.
5. The addition of wheat straw resulted in an increase in Shrinkage limit up to 10% of wheat straw content by about 114% approx.; it shows that the shrinkage limit is increasing with adding the WS content for freshly mixed samples. The addition of 2%wheat straw as a function of time indicates a slightly increasing trend in the shrinkage limit values.
6. The addition of lime resulted to increase the shrinkage limit up to 8% of lime content increase 149.5% then slightly decrease in shrinkage limit as a result of an increase in the lime content in the freshly mixed samples. The addition of 6% lime as a function of time indicates the increasing trend in the shrinkage limit as the time is passing.
7. The addition of wheat straw resulted to decrease in Linear Shrinkage up to 10% of wheat straw content by about 46.65% approx.; it shows that the linear shrinkage is decreasing with the addition of WS content for freshly mixed samples. The addition of 2% wheat straw as a

function of time indicates a slightly increasing trend in the linear shrinkage values.

8. The addition of lime resulted to a decrease in the linear shrinkage of a clayey soil. The decrease in the linear shrinkage is 67 % up to 10% of lime content in the freshly mixed samples; however, the addition of 6% lime indicates a slightly increasing trend in linear shrinkage as a function of time.

9. The addition of wheat straw resulted to decrease in volumetric Shrinkage up to 8% of wheat straw content by about 62.1% approx.: however, it shows a slightly increasing trend in the volumetric shrinkage by the increase in wheat straw content in the freshly mixed samples. The addition of 2% wheat straw as a function of time indicates increasing trend in the initial days; however, it shows a slightly decreasing trend in the volumetric shrinkage values as a function of time thereafter.

10. The addition of lime resulted to a decrease in the volumetric shrinkage in the clayey soil. The decrease in the volumetric shrinkage is about 65% up to 10% of lime content in the freshly mixed samples. The addition of 6% lime indicates fluctuating results in the initial month; however, thereafter it shows a continuously decreasing trend in the volumetric shrinkage as a function of time.

11. The addition of wheat straw resulted to decrease in shrinkage ratio up to 10% of wheat straw content by about 41% approx. for freshly mixed samples. The addition of 2% wheat straw as a function of time indicates a slightly increasing trend in shrinkage ratio.

12. The addition of lime resulted to decrease the shrinkage ratio with the addition of lime content. The decrease in the shrinkage ratio is 27% up to 10% of lime content in the freshly mixed samples. The addition of 6% lime as a function of time shows a slight decrease in the shrinkage ratio of a clayey soil.

13. Wheat straw resulted to a drastic decrease in the number and width of the shrinkage cracks; however, the addition of lime resulted to increase in the number of cracks and a slight decrease in the width of the cracks.

9. Conclusions

From the experimental results and brief summary it may be concluded that the addition of lime and wheat straw resulted to the following effects on the consistency and shrinkage parameters of clayey soil:

1. Wheat straw resulted to increase in OMC, PI (upto 2% WS content), shrinkage limit, linear shrinkage (as a function of time), and shrinkage ratio (slightly increasing as a function of time).

2. Wheat straw resulted to a decrease in average specific gravity, linear shrinkage, volumetric shrinkage, the shrinkage ratio of freshly mixed specimens and Wheat straw drastic decrease in the number and width of the shrinkage cracks.

3. Wheat straw resulted in no significant change in the PI-value (wheat straw content greater than 2% and as a function of time as well),

4. Lime resulted to increase in average specific gravity, OMC, PI (up to 1% lime content in the fresh mix and a function of time up to one month), shrinkage limit (up to 8% lime content in the fresh mix and as a function of time) linear shrinkage (as a function of time), and number of shrinkage cracks.

5. Lime resulted to decrease in PI-value (lime content greater than 1% in fresh mix), shrinkage limit (lime content greater than 8% fresh mix), linear shrinkage (fresh mix), Volumetric shrinkage (fresh mix and after one month as function of time), shrinkage ratio (fresh mix), shrinkage ratio slightly decrease (as a function of time) and width of shrinkage cracks.

6. Lime resulted in a fluctuation in the PI-value (as a function of time).

7. The study of the effect of lime and wheat straw on the consistency characteristics have shown that the shrinkage and swelling of clayey soils which resulting to several problems in the civil engineering infrastructures may be adequately managed by mixing an appropriate amount of lime and wheat straw as soil stabilizing agent for immediate and long-term effects.

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Conflicts of interest

The authors declare no conflict of interest.

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