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EFFECT OF LIME AND STONE DUST IN THE GEOTECHNICAL PROPERTIES OF BLACK COTTON SOIL

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ABSTRACT: In the present study Black Cotton Soil was stabilized with a mixture of lime and Stone Dust. First an optimum value of lime was determined on the basis of some geotechnical properties of mixture of lime and Black Cotton Soil. Then Stone Dust was mixed upto 25% by weight with an increment of 5% in the optimized mixture of lime-Black Cotton Soil. California bearing ratio, unconfined compression strength and maximum dry density values were determined of these modified mixes. Morphology of the soil and admixture has been studied by Scanning electron microscope (SEM), while mineralogical composition has been determined by X-Ray diffraction technique (XRD).

Keywords: *Black Cotton Soil, Geotechnical properties, California bearing ratio (CBR), scanning electron microscopic (SEM) and X-ray diffraction (XRD)*

1. INTRODUCTION

Every year many civil engineering structures like buildings, embankments, roads and dams constructed on expansive soils got damaged due to highly expansive behavior of such soils. The main reason behind such behavior of expansive soils is the presence of mineral called montmorillonite. It has high water content capacity and swells significantly when it comes in contact with water. In India expansive soils are also known as Black Cotton Soils as cotton is cultivated in majority of the areas where this black soil is found. It covers around 20% of total land area of India. It is largely found in southern, western and central parts of India, covering Andhra Pradesh, Karnataka, Gujarat and some parts of Madhya Pradesh. The construction on Black Cotton Soil has always been a big challenge to geotechnical engineers. Many researchers have worked to improve or stabilize its expansive behavior with various admixtures. They have used waste materials as admixtures and showed their best results in soil stabilization. Modak et. al [1] studied the combined effect of lime and fly ash in Black Cotton Soil and concluded that with increasing the percentage of lime and fly ash in Black Cotton Soil, California bearing ratio (CBR) and maximum dry density (MDD) values are also increases. Nadgouda and Hegde [2] found optimum value of CBR and MDD at 3.5 % lime addition in Black Cotton Soil. Ijimdiya et. al [3] stabilized the Black Cotton Soil by groundnut shell ash (GSA) and observed that unconfined compressive strength increased from 91 kN/m^2 without adding GSA to a maximum value of 211 kN/m^2 at 8% GSA, whereas the optimum value of CBR was found on the addition of 6.3% of GSA.

Calcium oxide (CaO) known as quicklime is a widely used chemical compound. It is a white, caustic and alkaline crystalline solid at room temperature. As a commercial product, lime often also contains magnesium oxide, silicon oxide and smaller amounts of aluminium oxide and iron oxide (refer Table I for a typical chemical composition).

Lime in the form of quicklime (calcium oxide - CaO), hydrated lime (calcium hydroxide –$Ca(OH)_2$), or lime slurry can be used to treat soils. Quicklime is manufactured by chemically transforming calcium carbonate (limestone-$CaCO_3$) into calcium oxide. Hydrated lime is created when quicklime chemically reacts with water (refer Table II for comparison). It is hydrated lime that reacts with clay particles and permanently transforms them into a strong cementitious matrix. Usually, limes used for soil treatment are "high calcium" limes, which contain no more than 5 percent of magnesium oxide or hydroxide. Lime, either alone or in combination with other materials, can be used to treat a range of soil types (Sarkar et. al [4]).

Again, the annual generation of quarry dust is roughly around 200 million tons in India (Soosan et. al [5]). Limited researches are available regarding the utilization of Stone Dust with lime for stabilization of expansive soils. So, in the present study, lime and Stone Dust was used as admixtures for Black Cotton Soil. The maximum dry density (MDD) and optimum moisture content (OMC), California bearing ratio (CBR) and unconfined compression strength (UCS) characteristics were studies. The present study aims towards showing how these two above materials can be utilized in Black Cotton Soil in an optimum way to assure a win-win condition for both soil stabilization and quarry waste disposal.

2. MATERIAL USED

2.1 BLACK COTTON SOIL

Table I Chemical composition of lime (Sarkar et. al. [5])

Properties	Test value (%)
Minimum Array (Acidimetric)	95.00
Maximum Limits of Impurities	
Chloride (Cl)	0.10
Sulphate (SO_4)	0.50
Iron (Fe)	0.10
Lead (Pb)	0.02
Loss on Ignition	10.0

Table II Index properties of quicklime and hydrated lime (Sarkar et. al [5])

Properties	Quicklime	Water	Hydrated lime
Molecular weight	56	18	78
Specific gravity	3.3	1	2.2
Relative weight	1	0.32	1.32
Relative volume	1	-	1.99

For the present study, Black Cotton Soil sample were collected from Gwalior-Jhansi road, near Tekanpur BSF area (National Highway No. - 7), Gwalior.The top layer of the soil was removed with the help of shovel up to a depth of 0.5 m before collecting the soil sample. The geotechnical properties of Black Cotton Soil sample used in this study are given in Tables III.

2.2 STONE DUST

Bulk quantities of Stone Dust were procured from stone crusher plant of Aman vihar Industrial area, New Delhi.

2.3 LIME

The lime was procured from the local market. The chemical composition of lime is mentioned in Table I.

3. EXPERIMENTAL INVESTIGATIONS

3.1 INTRODUCTION

Bulk quantities of Black Cotton Soil in wet state were collected from the sites of Gwalior-Jhansi road. The samples were collected personally and procured freshly at the beginning of the study and stored properly.

Table III Geotechnical properties of Black Cotton Soil

Properties	Value
Specific Gravity	2.61
Percentage passing IS Sieve 75 micron (%)	58.0
Liquid Limit (%)	57.0
Plastic limit (%)	31.4
Plasticity index (%)	26.5
Differential Free Swell (%)	41.0
Unified Soil Classification System (USCS)	CH
Maximum dry density (kN/m^3)	16.1
CBR (soaked) (%)	1.50
Unconfined compression strength, (kN/m^2)	166.2

The collected soil samples were characterized in the geotechnical laboratory of Delhi Technological University. Tests were conducted to determine physical and geotechnical properties of soil samples. The specific gravity tests were performed on Black Cotton Soil, lime and Stone Dust. The standard Proctor tests were also performed on soil samples alone as well as their mixes with an increasing percentage of lime by weight (3, 6, 9 and 12 percentage) and maximum dry density (MDD) was calculated to determine the optimum percentage of lime to be mixed with the soil. After determining optimum percentage of lime (=9%), Stone Dust was mixed by 5, 10, 15, 20 and 25% by weight in the lime-Black Cotton Soil mix to determine MDD and OMC, unconfined compression strength (UCS) and California bearing ratio (CBR) value of the new mix. The details of the experimental program are summarized in Table IV. The tests were performed conforming to Indian standard specifications listed in Table V.

3.2 DETAILS OF TESTS CONDUCTED

3.2.1 Specific gravity

The specific gravity of the soil was determined as per Indian standard specifications [6].

3.2.2 Grain size distribution

The grain size distribution of soil was carried out as per the Indian standard specifications [7].

3.2.3 Atterberg limit test

All the tests for Atterberg limits were conducted as per the Indian standard specifications [8]. Liquid limit tests were carried out using Casagrande's equipment.

3.2.4 Differential free swell (DFS) index

Differential free swell index of soil sample was determined by Indian standard specification [9]. Free swell index is used for the classification of the expansive soils on the basis of degree of expansiveness.

3.2.5 Compaction characteristics

Light (standard Proctor) test were carried out to determine the maximum dry density (MDD) and optimum moisture content (OMC) of soil and treated soil as per Indian standard specifications [10].

Table IV Experimental program

Material	Details of experiments
Black Cotton Soil	a) Specific gravity
	b) Atterberg limit tests
	c) Differential free swell test
Black Cotton Soil alone and mixed with lime and Stone Dust	d) Standard Proctor test
	e) California bearing ratio test
	f) Unconfined compression strength test

Table V: Standard codes used to perform laboratory tests

Laboratory tests	Standard/Procedures
Specific gravity	IS: 2720 (Part 3) – 1980
Grain size analysis	IS: 2720 (Part 4) – 1985
Atterberg limit test	IS: 2720 (Part 5) – 1985
Differential free swell index	IS: 2720 (Part 40) – 1977
Standard Proctor compaction test	IS: 2720 (Part 7) – 1980
California Bearing Ratio test	IS: 2720 (Part 16) – 1987
Unconfined compressive strength test	IS: 2720 (Part 10) – 1973

3.2.6 California Bearing Ratio (CBR) test

California bearing ratio (CBR) tests were conducted on soil and treated soils as per Indian standard specifications [11]. The California bearing ratio test is a penetration test that measures the subgrade strength of soils used for roads and pavements (Sarkar et. al [4]). The results obtained by CBR tests are used with empirical curves to determine the thickness of pavement and its component layers. It is the most widely used method for the design of flexible pavements.

3.2.7 Unconfined Compression Strength (UCS) test

Unconfined compression strength tests were conducted on soil and treated soils as per Indian standard specifications [12]. The UCS test evaluates the compressive strength of cohesive soil in unconfined state and very necessary for the determination of load carrying capacity of foundation, embankment etc.

3.3 TEST RESULTS AND DISCUSSION

3.3.1 Specific Gravity

The specific gravity of Black Cotton Soil, lime and Stone Dust were found 2.61, 3.22 and 2.75, respectively.

3.3.2 Atterberg limit test

The liquid limit of Black Cotton Soil was found to be 57% and plastic limit was found 31.43 %. According to Unified Soil Classification System (USCS), soil can be classified as highly compressible soil (CH).

3.3.3 Differential free swell test

The differential free swell index of Black Cotton Soil was found 41%.

3.3.4 Compaction behavior

Light compaction tests were conducted on the natural and treated soil in the investigation to determine MDD and OMC value. Fig. 1 shows the variation of MDD with percentage of lime. It is observed that MDD value is increases from 16.1 kN/m^3 to 16.6 kN/m^3 when no lime is added and 9% lime is added, respectively, and it decreases afterwards. Lime causes the soil particles to coagulate, aggregate, or flocculate. Thus soil becomes more easily workable and its strength and stiffness increases up to a certain value. The MDD values are 16.2 kN/m^3, 16.4 kN/m^3, 16.6 kN/m^3 and 16.5 kN/m^3 for the soil mixed with 3%, 6%, 9% and 12% lime, respectively.
Figure 2 shows the variation of MDD with percentage of Stone Dust in soil-lime (=9%) mix. It is observed that MDD of lime stabilized soil increases upto addition of 20% Stone Dust and further addition of Stone Dust decreases the MDD value. This can be due to the mixing of heavy particles of Stone Dust in significant amount. Beyond addition of 20% Stone Dust in lime stabilized soil, the strength decreases since large Stone Dust content segregates the particles and maximum dry density decreases.

3.3.5 California Bearing Ratio (CBR) test

Soaked CBR tests were conducted on Black Cotton Soil and soil mixed with admixtures as per Indian Standards. Sample was prepared in cylindrical mould and compacted in five layers. Then the compacted sample along with mould was submerged in water for 72 hours. After removing from water, the CBR test was performed under a constant strain rate of 1.25 mm/min. Fig. 3 shows the variation in CBR with percentage of lime.

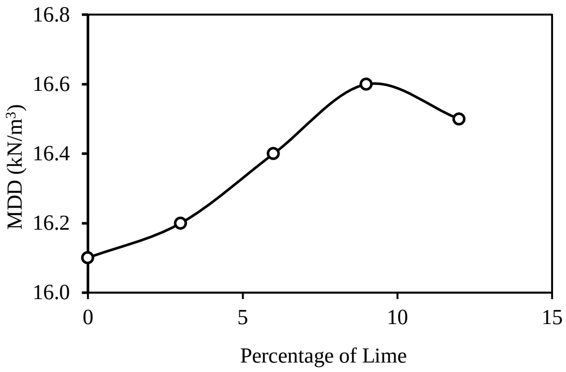


Fig. 1 Variation of MDD with percentage of lime

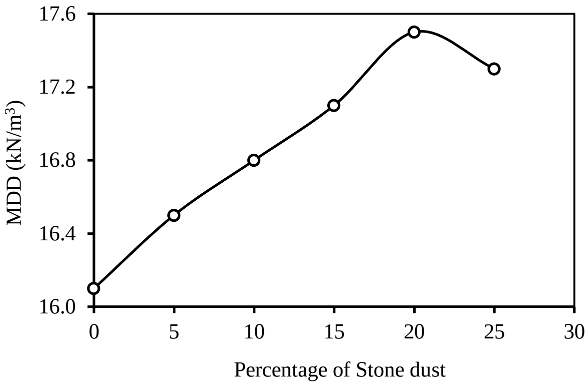


Fig. 2 Variation of MDD with percentage of Stone Dust in soil-lime (=9%) mix

The CBR value is 1.5% when no lime is added in the soil. The CBR values are 3.9%, 7.6%, 12.8% and 12.0% for the soil mixed with 3%, 6%, 9% and 12% lime, respectively. It is noted that as observed in case of variation of MDD with percentage of lime (Fig. 1), the CBR value is also increases upto 9% addition of lime in soil and then decreases.

Figure 4 shows the variation of CBR with percentage of Stone Dust in soil-lime (=9%) mix. It is observed that the soaked CBR value attains highest value when 20% of Stone Dust was added in lime stabilized soil and then decreases.

As mentioned above, addition of Stone Dust in the soil-lime (=9%) mix up to 20%, increases the CBR value since silica in all the finer particles of soil and Stone Dust are used up to this value and addition of more Stone Dust actually becomes counterproductive thereafter.

3.3.6 Unconfined Compression Strength (UCS) test

Unconfined compression tests were conducted on soil and treated soils as per Indian Standards. Samples were prepared in split mould at MDD and optimum moisture content (OMC). The cylindrical specimen of soil and treated soil were tested under normal vertical load. The UCS value of every sample was determined by dividing the maximum load at which the failure takes place and the corrected cross sectional area of the specimen. Fig. 5 shows the variation of UCS with percentage of lime. It is observed that the UCS value increases upto the 9% addition of lime and then decreases. The UCS value is 154 kN/m^2 when no lime is added in soil. The UCS values are 159 kN/m^2, 164 kN/m^2, 169 kN/m^2 and 166 kN/m^2 for the soil mixed with 3%, 6%, 9% and 12% lime, respectively. The optimum value of MDD of soil occurred at 9% lime addition.

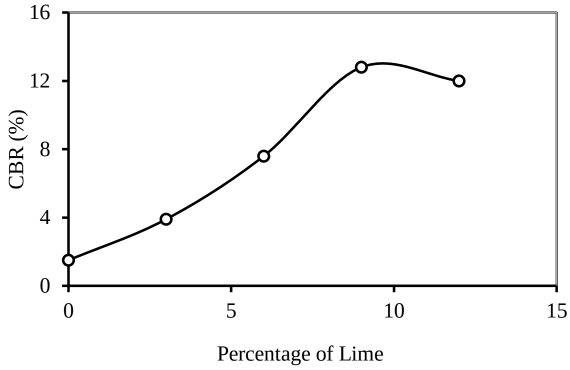


Fig. 3 Variation of CBR with percentage of lime

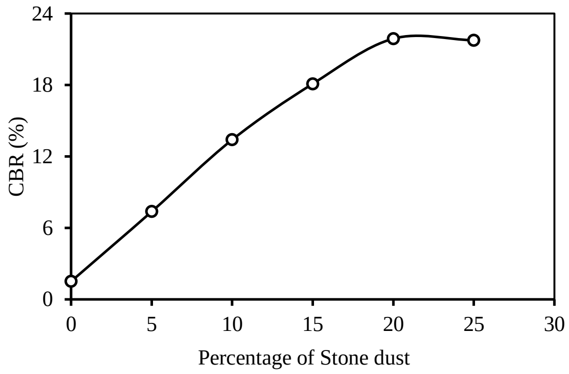


Fig. 4 Variation of CBR with percentage of Stone Dust in soil-lime (=9%) mix

Figure 6 shows the variation of UCS with percentage of Stone Dust in soil-lime (=9%) mix. It is observed that UCS value increased from 154 kN/m^2 to 182 kN/m^2 when no Stone Dust is added and 20% of Stone Dust is added, respectively, and it decreases afterwards. It is due to the addition of Stone Dust beyond 20% gives the negative effect to the UCS value of lime stabilized soil.

3.4 MORPHOLOGY

The morphology of the Black Cotton Soil and admixtures were analyzed by Scanning Electron Microscopic (SEM) Hitachi S 3700. Samples were taken after 28 days of curing. Referring Fig. 7(a)-(e), it is clearly visible that from the micrograph Black Cotton Soil, lime and stone dust have undergone pozzolanic reaction, stone dust and lime particles accumulated over the Black Cotton Soil and forming the various cementitious compounds.

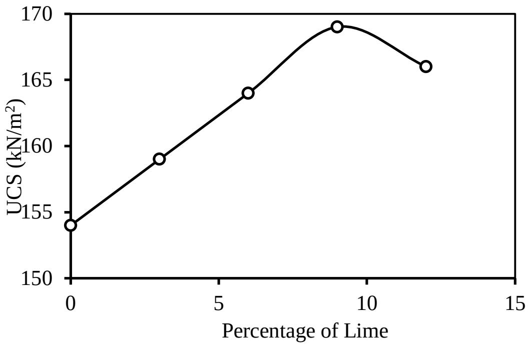


Fig. 5 Variation of UCS with percentage of lime

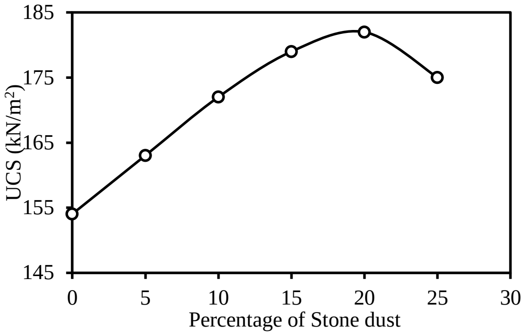
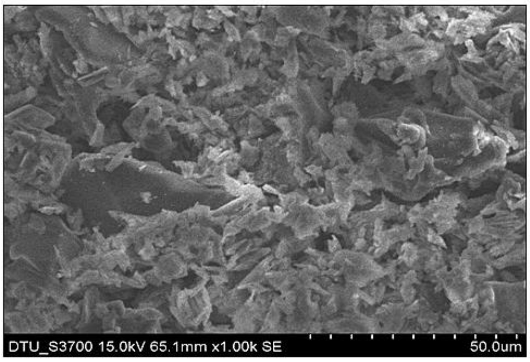


Fig. 6 Variation of UCS with percentage of Stone Dust in soil-lime (=9%) mix

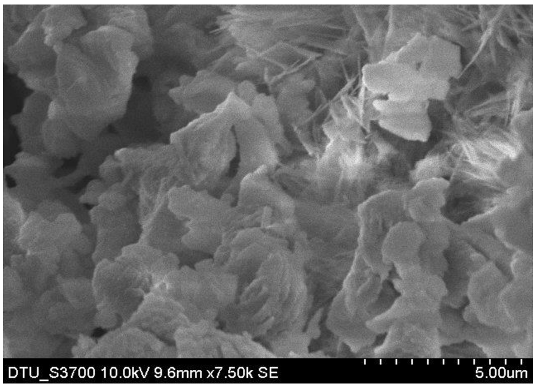
3.5 MINERALOGICAL CHARACTERIZATION

The pozzolanic reaction between soil and admixtures, results in the change in mineralogical phases of soil. Hence, the mineralogical analysis of the treated soil becomes very essential. Therefore, XRD-analysis was conducted on the treated soils. Test was conducted with the help of X-Ray diffractometer, Hitachi, which employ a Cu-Kα radiation (step of 0.05° 2θ and range of 0°-70° 2θ). Sulphate present in the soil reacts with calcium (from lime) and alumina (from stone dust and clay) forms the mineral ettringite. This ettringite mineral improves the soil strength and reduce the swelling tendency of the soil. The description of the sequence given by (Hunter in 1988) as

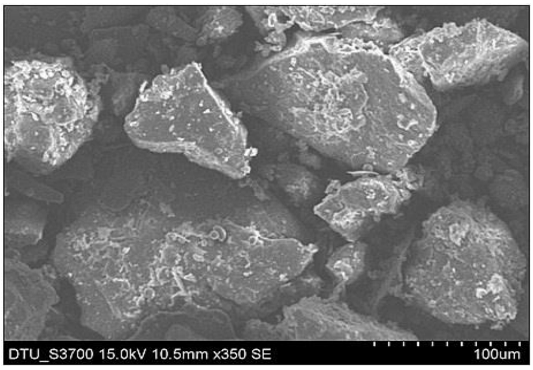
$$6Ca + 2Al\,(OH)^{-}_{4} + (OH)^{-} + 3(SO_4)^{2-} + 26H_2O \longrightarrow Ca_6\,[(Al(OH)_6)]_2\,(SO_4)_3\,.\,26H_2O$$



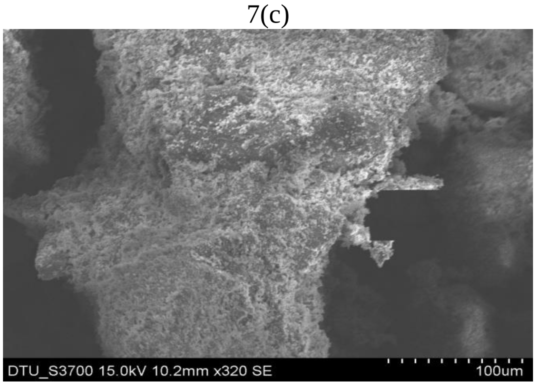
7(a)



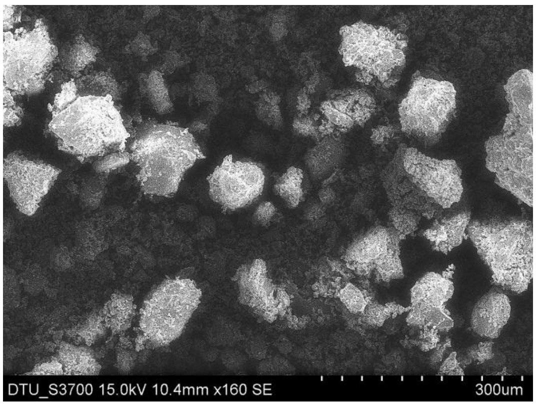
7(b)



7(c)



7(d)



7(e)

Figure 7 Scanning electron micrographs of (a) Black Cotton Soil (b) Lime (c) Stone Dust (d) Black Cotton Soil + 9 % (e) Lime Black Cotton Soil + 9 % Lime + 25% Stone Dust

Figure 8(a)-(c) shows the X-Ray Diffraction patterns of Black Cotton Soil, Stone Dust and Black Cotton Soil mixed with Lime (9%) and Stone Dust (25%), respectively.

4. CONCLUSION

Black Cotton Soil and admixtures were identified by experimental studies. The changes in their physical properties were studied with the help of laboratory tests. The following conclusions can be obtained by test results data.

1. It is observed that MDD of lime stabilized (=9%) Black Cotton Soil increases up to the addition of 20% Stone Dust and further increase of the agent decreases the value.
2. Similarly, for UCS and CBR, the strength increases upto 20% addition of Stone Dust in lime stabilized soil. The reason of this effect is the pozzolanic reactions of lime with the amorphous silica and alumina present in soil and Stone Dust.
3. SEM Pictures of cured sample clearly shows coarser bonded particles of Black Cotton Soil , Lime and Stone Dust
4. X-Ray diffraction of samples shows the presence of montmorillonite, vermiculite (minerals of smectite group), in Black Cotton Soil, whewellite and Quartz in Stone Dust and dolomite calcite in lime.

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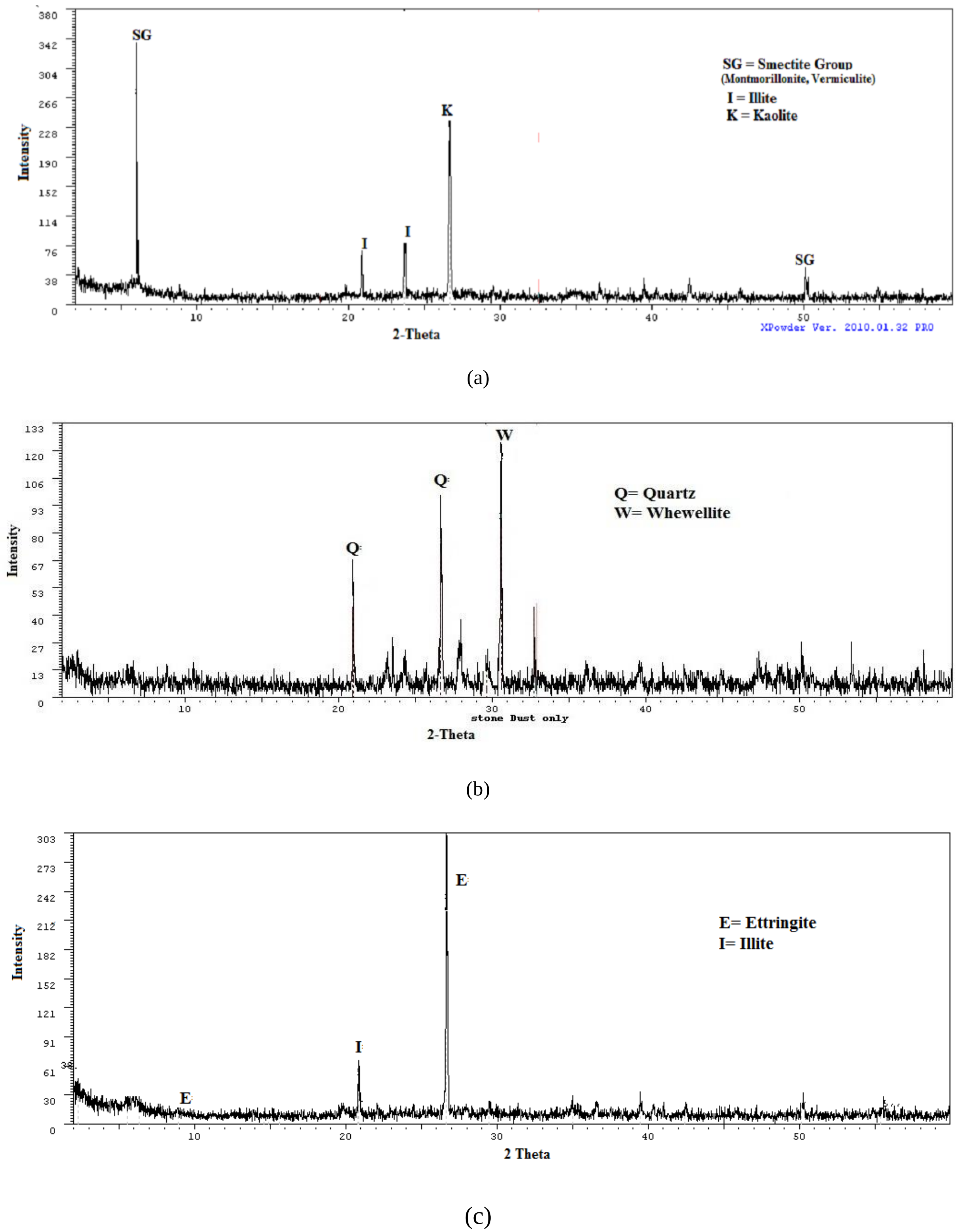

Figure 8 X-Ray Diffraction patterns of (a) Black Cotton Soil (b) Stone Dust (c) Black Cotton Soil + 9% Lime + 25% Stone Dust