The Effects of Various Lime Products for Soil Drying

Lawrence W. Cole, P.E.
Technical Marketing Manager—Construction

Timothy Shevlin
Technical Specialist—Construction

Steve Tutokey
Senior Technical Service Technician

Joel Beeghly
Senior Technical Specialist

Carmeuse Lime Company
3600 Neville Road
Pittsburgh, Pennsylvania 15225
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ABSTRACT

One common challenge faced by earthwork and paving contractors is overly wet soil conditions. Wet, in-place site soils serving as the subgrade for roadway, airfield, or parking lot pavements will pump and not be of sufficient strength to carry construction vehicles and traffic loads. Further, existing site soils are often excessively wet to be properly compacted as fill for embankments, building slabs and other facilities.

Lime is a very effective drying agent that quickly lowers the soil moisture content. Additionally, lime modifies the structure of the clay portion of soil, changing the optimum moisture content (OMC). This combined effect – lowering the soil moisture content and increasing the OMC – makes lime an effective drying agent.

This laboratory study evaluated the effects of five lime products — two quicklime, hydrated lime and two lime kiln dusts (EnviroLime®) – for “soil drying” of four soils of differing plasticity indices (PI). A number of observations are offered, including: comparative effects of the various lime products, the variation in the amount of “soil drying” as related to soil PI, the speed at which “soil drying” occurs, and the effects of a second mixing operation to remix the lime and soil after a 24 hour mellowing period.

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INTRODUCTION

One common challenge faced by earthwork and paving contractors is overly wet soil conditions. Wet, in-place site soils serving as the subgrade for roadway, airfield, or parking lot pavements will pump and not be of sufficient strength to carry construction vehicles and traffic loads. Further, existing site soils to be placed as fill for embankments, building slabs, and other facilities are often excessively wet to be properly compacted. Such soil must be replaced or adequately dried to meet project specifications. Replacing overly wet soil is an expensive, often unbudgeted, operation. Construction delays occur while waiting for the soils to dry naturally. A cost-effective alternative is to add a chemical agent that will dry the soils in-place.

Lime is a very effective drying agent that quickly lowers the soil moisture content. Additionally, lime modifies the structure of clay soils making them more friable, changing the optimum moisture content (OMC), and altering other soil engineering characteristics (1). The addition of lime typically increases the OMC of soils while decreasing soil moisture content (2). The OMC-increase allows the soil to be compacted at higher moisture content. The combined effects of soil moisture reduction and the increase of soil OMC are beneficial for soil drying. Adding lime to soil containing clay also makes the soil more friable in nature, allowing clay soils to be more easily worked and compacted.

While the soil-drying benefits of lime are well known, many facets are not well documented – particularly the comparative effects of different lime products. Additionally, there is little documented information on how quickly lime acts to dry the soil. This is important so that compaction efforts can begin as soon as the soil has reached the desired moisture content.

PURPOSE AND SCOPE OF THE STUDY

The purpose of this laboratory study was to gain insight into the effects of various lime products to “dry” different soil. “Soil drying” by the addition of lime involves two changes that occur when lime is introduced into the soil:

1. The soil moisture content decreases, and
2. The soil’s optimum moisture content increases.

Both must be studied as it is the combined effect of these phenomena that impact further construction operations.

Soil Used in Study

Four soils were chosen for the study. While a number of soil characteristics could have been selected to differentiate the soil, plasticity index (PI) was the primary differentiator selected for this study. Some of the key soil characteristics are shown in Table 1.

Lime Products Used in Study

Laboratory tests were made with five lime products:

1. High calcium quicklime (High cal quicklime) meeting the requirements of ASTM C 977 (3).
2. Dolomitic quicklime (Dolo quicklime) meeting the requirements of ASTM C 977 (3).
3. Hydrated high calcium lime (Hydrate) meeting the requirements of ASTM C 977 (3).
4. Lime kiln dust from the production of high calcium quicklime (High cal LKD).
5. Lime kiln dust from the production of dolomitic quicklime (Dolo LKD).

<table>
<thead>
<tr>
<th>General Location of Source of Material</th>
<th>Unified Soil Classification Group</th>
<th>AASHTO Soil Classification Group</th>
<th>Plasticity Index (%)</th>
<th>% Clay Content</th>
<th>Optimum Moisture Content (%)</th>
<th>Maximum Dry Density (pcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicago O’Hare Airport Northern Illinois</td>
<td>SC</td>
<td>A-2-6</td>
<td>7</td>
<td>32</td>
<td>12.2</td>
<td>122</td>
</tr>
<tr>
<td>US Highway 30 North-Central Ohio</td>
<td>CL</td>
<td>A-6</td>
<td>22</td>
<td>72</td>
<td>15.9</td>
<td>112</td>
</tr>
<tr>
<td>Dulles Airport Area Northern Virginia</td>
<td>CL</td>
<td>A-6</td>
<td>26</td>
<td>77</td>
<td>20.6</td>
<td>104</td>
</tr>
<tr>
<td>Prince William County Northern Virginia</td>
<td>CH</td>
<td>A-7-6</td>
<td>37</td>
<td>87</td>
<td>24.8</td>
<td>95</td>
</tr>
</tbody>
</table>
Some of the key properties of the lime products used in this study are shown in Table 2.

According to the National Lime Association (4), high calcium quicklime is derived from high calcium limestone and principally contains calcium oxide and less than 5 percent magnesium oxide (MgO). Dolomitic quicklime is derived from dolomitic limestone and principally contains calcium oxide and 35-40 percent magnesium oxide (4).

Lime kiln dust is a fine-grained co-product of lime production. LKD is most commonly generated in high temperature rotary kilns and captured in the air pollution systems such as baghouses, cyclones and electrostatic precipitators. LKD contains, among other components, calcium oxide and magnesium oxide. In North America, Carmeuse Lime markets lime kiln dust under the trademark, EnviroLime®.

Mixing the Soil and Lime Products

In this study, each of the soils was moistened to approximately 8% above OMC before the lime was added. The lime products were individually added to a portion of the moistened soil at 4% by dry weight of soil. After the initial mixing, the lime-soil mixtures were stored in air tight plastic bags at room temperature. The moisture content was determined for each soil-lime mixture at 1 hour, 4 hours and 24 hours. Also, after 24 hours each soil-lime mixture was remixed and the moisture content was again determined. This allows for a determination of the effects of a second mixing 24 hours after the initial mixing. The soil OMC was determined 4 hours and 24 hours after initial mixing.

The soil and lime products were mixed at room temperature using a Hobart mixer. The soil and lime products were mixed until the soil-lime mixture appeared thoroughly consistent throughout the mixture, based on visual observations. It is important to note that complete blending of the lime products and soil was sought. It is known that thorough mixing is key to successful incorporation of lime into soil during construction operations (4), but no attempt was made to relate these laboratory mixing procedures to field mixing. Such comparisons were beyond the scope of this study. It should also be noted that all mixing and subsequent measurements were made at room temperature. No efforts were made in this study to evaluate the lime products’ soil drying effects as related to soil temperature conditions.

The Dual Aspects of Adding Lime Products to Soil for Soil Drying

The effects of lime to reduce the soil moisture content are clearly important when considering lime for drying an overly wet soil. Lime quickly lowers the soil moisture content – drying the soil. The second effect – increasing the soil’s OMC — is less apparent, but equally or more important. By increasing the OMC, more moisture can be accommodated during compaction operations. These effects are complementary when soil drying is the goal.

For instance, let us assume that an untreated soil has an optimum moisture content of 24%. In the field, assume the soil is at 32% moisture content – 8% above OMC. If adding lime decreases the moisture by 3%, the moisture content would be 29%. If the lime also increases the soil’s OMC by 5%, the OMC of lime-treated soil has changed – the new OMC is 29%. Lime has decreased the soil moisture content by 3% while also increasing the OMC by 5% and the soil is now at OMC for compaction – 29% moisture content.

### TABLE 2  Key Properties of Lime Products Used in Study

<table>
<thead>
<tr>
<th>Designation</th>
<th>Source</th>
<th>Available Lime Content (% per ASTM C25)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Calcium Quicklime (High Cal Quicklime)</td>
<td>Carmeuse Lime Plant Annville, Pennsylvania</td>
<td>90</td>
</tr>
<tr>
<td>Dolomitic Quicklime (Dolo Quicklime)</td>
<td>Carmeuse Lime Plant Chicago, Illinois</td>
<td>57</td>
</tr>
<tr>
<td>Hydrated Lime</td>
<td>Hydrated High Calcium Lime</td>
<td>Not Determined</td>
</tr>
<tr>
<td>EnviroLime® (High Calcium Lime Kiln Dust)  (High Cal LKD)</td>
<td>Generated during the production of high calcium quicklime at Carmeuse Lime Plant, Annville, Pennsylvania</td>
<td>28</td>
</tr>
<tr>
<td>EnviroLime® (Dolomitic Lime Kiln Dust)     (Dolo LKD)</td>
<td>Generated during the production of dolomitic quicklime at Carmeuse Lime Plant, Chicago, Illinois</td>
<td>16</td>
</tr>
</tbody>
</table>
It is this “net” effect – the change in moisture plus the change in OMC – that makes lime an effective soil drying agent. Therefore, these combined effects must be recognized and studied to properly evaluate the effects of the various lime products to “dry” the soil.

**Effects of Lime to Reduce Soil Moisture Content**

It is generally recognized that lime products reduce soil moisture content (5,6). This is thought to occur from a combination of:

1. **Dilution** – adding dry lime material to moist soil.
2. **Lime hydration** – the rapid hydration of calcium oxide – CaO – into calcium hydroxide – Ca(OH)₂.
3. **Evaporation** – the exothermic reaction of lime hydration increases moisture evaporation.
4. **Pozzolanic reactions** – the chemical reactions between calcium hydroxide and the alumina and silica compounds that are present in most clay soils. While this is generally thought to be a long term chemical reaction, the chemical reaction between the lime and the silica and alumina compounds in the soil may “tie up” the soil moisture as these reactions begin.

**Effects of Lime to Increase the Soil’s Optimum Moisture Content**

The effects of lime to increase soil optimum moisture content are well documented (1,2,6), although the reason for this increase is not discussed. We contend that this increase in OMC can likely be contributed to “soil modification” – the changes in soil texture induced by cation exchange.

Cation exchange and the resulting flocculation/agglomeration of the clay portion of soil due to the addition of lime are well documented (1,2,7). One of the results of cation exchange and flocculation/agglomeration of the clay particles is a textural change as clay particles are rearranged from a parallel alignment to edge-to-face attraction (7). This new texture allows for more void space which can accommodate more water during compaction.

**Reduction in Soil Moisture Content Due to the Addition of Lime**

Figure 1 shows the reduction in soil moisture content four hours after the various lime products have been introduced into the soil samples. In general, the high calcium quicklime lowered soil moisture content more than the other lime products, typically about 0.5% more than the dolomitic quicklime and 1% - 1.5% more than the hydrated lime or LKD. The high calcium LKD and dolomitic LKD decreased the soil moisture content about the same amount, while hydrated lime was generally slightly less effective than the lime kiln dusts. These are the expected trends and are likely due to the differing amounts of calcium oxide – CaO – in the lime products that reacts with water from the soil as hydration occurs.

Adding dry material to the moist soil should lower the moisture content due to dilution. Adding 4% dry material to these soils that are 8% above OMC should lower the soil moisture content decrease. The reduction in soil moisture content due to dilution is shown in Figure 1.

![Figure 1: Soil Moisture Content Decrease 4 Hours After Mixing.](image-url)
moisture content by about 1%. For an equal amount of lime, the decrease in moisture content due to the hydration of the CaO in the lime products should vary depending on the amount of CaO in the lime product. The CaO content ranges from about 90% CaO in the high cal quicklime to effectively 0% CaO in the hydrated lime. Each pound of CaO will chemically bind about 0.34 pounds of water during hydration. As an estimate, at this application rate (4%), high calcium quicklime should reduce the soil moisture content by about 1% due to CaO hydration while hydrated lime will not lower the soil moisture content due to CaO hydration. The other lime products should lower the soil moisture content between 0% and 1% depending on the CaO content.

Therefore, the expected decrease in soil moisture content from dilution and CaO hydration should be about 2% for quicklime, 1% for hydrated lime and between 1% and 2% for the other lime products for these study conditions.

It is interesting to note the decreases in soil moisture content was generally within this range or slightly more. The exception was the soil “PI = 37.” For this soil, all lime products lowered the soil moisture content considerably more than can be attributed to dilution and lime hydration. This indicates that some other chemical reactions occurred in this soil to cause moisture reduction in a short time period. We suggest that this was due to the early formation of poz- zolanic compounds – particularly calcium-alumina-hydrates. Further investigation of this postulation is beyond the scope of this study.

Reduction of Moisture Content with Time

Figure 2 shows the reduction of the soil moisture content at different times after the addition of 4% of the various lime products into the “PI = 37” soil. With thorough mixing, nearly all of the total decrease in soil moisture occurred within the first 1 to 4 hours after mixing. All of the decrease in soil moisture content from the addition of high cal quicklime occurred within the first hour after mixing. Similar results were noted for high calcium quicklime with the other soils.

The decrease in moisture content due to the addition of all lime products occurred rapidly. In nearly all cases, between 85% -100% of the 24-hour decrease in moisture content occurred within the first 4 hours. In fact, the large majority occurred within one hour of mixing.

Increase in Optimum Moisture Content

The increase in soil optimum moisture content measured four hours after mixing 4% of the lime products into the soil is shown in Figure 3. The results were quite variable. Some general trends appeared for three of the four soils – PI =7, PI = 22 and PI = 26:

- All lime products were effective in increasing the soil OMC.
- The change in OMC was greater as the PI of the soil increases.

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**FIGURE 2 Effect of Time on the Decrease in Soil Moisture Content After Lime Addition**

![Graph showing the decrease in soil moisture content with time](image-url)

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FIGURE 3 Effect of Lime Product on the Increase in Optimum Moisture Content
Within practical measuring limits, all lime products were virtually equally effective in increasing the soil OMC. Again, the exception appears to be the “PI = 37” soil. At the 4% addition rate, high calcium quicklime was much more effective in increasing the soil OMC for the “PI = 37” soil, while dolomitic LKD was not as effective as the other lime products. Dolomitic quicklime, hydrated lime and high calcium LKD all increased the “PI = 37” soil’s OMC in a similar manner.

The Combined Effects of Moisture Content Reduction and OMC Increase

The combined effects of adding 4% of the lime products to decrease the soil moisture content and to increase the soil OMC is shown in Figure 4 for the soils at 4 hours after mixing. Some general observations appear:

- All lime products were effective for “soil drying” by decreasing the soil moisture content and increasing the soil OMC.
- The combined effect of moisture reduction and OMC increase can generally be related to the soil PI. This combined effect increased as the soil PI increased.
- For 4% high calcium quicklime, the combined moisture reduction and OMC increase ranged from about 4% to up to 11% for these soils. Again, the combined effect increased as the soil PI increased.

For the medium plasticity soils (PI = 22 and PI = 26):

- Quicklime – both high calcium and dolomitic – is somewhat more effective than hydrated lime and both LKDs for soil drying. The combined effect of decreasing the soil moisture content and increasing the OMC is 1% - 2% greater with quicklime than with LKD or hydrate lime.
- High calcium quicklime and dolomitic quicklime provide about the same amount of combined moisture decrease and OMC increase and were equally effective for “soil drying.”
- Hydrated lime, high calcium LKD and dolomitic LKD provided about the same amount of combined decrease in moisture content and OMC increase.

The combined effects of adding 4% of the lime products on the decrease in soil moisture content and the increase in soil OMC are shown in Figure 5 for the soils at 24 hours after initial mixing, followed by a second mixing. The general observations offered for these combined effects at 4 hours after mixing seem to be appropriate for 24 hours after mixing and remixing. It appears that some additional increase in the combined effect has occurred for some of the products.
FIGURE 4  Combined Effect of Soil Moisture Decrease and OMC Increase 4 hours After Mixing

FIGURE 5  Combined Effect of Soil Moisture Decrease and OMC Increase 24 hours After Mixing, then Remixing
Effect of Mellowing and Remixing on the Combined Effect of Soil Moisture Reduction and OMC Increase

Table 3 shows the effect of a 24-hour waiting, or “mellowing” period followed by a second mixing of the soil on the combined effects of soil moisture reduction and OMC increase. The values shown in Table 3 are ratio of the change in moisture content and OMC at 4 hours after initial mixing compared to change that occurs in 24 hours and a second mixing. For instance, for Soil “PI = 22” with 4% high calcium quicklime, 78% of the combined moisture reduction and OMC increase that occurred after 24 hours and two mixing operations actually occurred within the first 4 hours of the initial mixing.

As can be seen from Table 3, the large majority of the drop in moisture content and the increase in OMC occurred within the first 4 hours. Interestingly, the soils with the higher plasticity indices - PI = 26 and PI = 37 – showed the least benefit of mellowing and repeated mixing. This puts question to the common practice of requiring a 24 hour or longer mellowing period followed by a second mixing when the lime is thoroughly mixed into the soil in the initial mixing process and soil drying is the goal.

CONCLUSIONS

The effectiveness of lime products to chemically “dry” soil for further construction purposes has been substantiated in this study. In practical applications, the effect of lime for “soil drying” is two-fold – the lime decreases the soil moisture content and increases the soil’s OMC, allowing the soil to be compacted in a wetter condition. Both effects must be considered as it is this “net effect” – the change in moisture plus the change in OMC – that makes lime an effective soil drying agent.

Observations that can be made from this laboratory investigation of five lime products mixed with four soils of varying plasticity indices - thoroughly mixed at room temperature - include:

- All lime agents decreased the soil moisture content and increased the soil OMC.
- The decrease in soil moisture content is thought to be due to:
  1. Dilution – adding dry lime material to moist soil.
  2. Lime hydration – the rapid hydration of calcium oxide - CaO - into calcium hydroxide – Ca(OH)₂.
  3. Evaporation – the exothermic reaction of lime hydration increases moisture evaporation.
  4. Pozzolanic reactions – the chemical reactions between calcium hydroxide and the alumina and silica compounds that are present in most clay soils.
- The decrease in soil moisture content occurred rapidly, mostly within the first hour of mixing.
- The change in the soil OMC is thought to be due to cation exchange and the resulting flocculation/agglomeration of the clay portion of the soil due to the addition of lime.
- The amount of change in OMC was greater for soil with higher PI.
- The combined effect of soil moisture reduction and OMC increase can generally be related to the soil PI. This combined effect increased as the soil PI increases.
- At four hours after initial mixing: Hydrated lime, high calcium LKD and dolomitic LKD provided about the same amount of combined decrease in moisture content and OMC increase in moisture content and OMC increase were equally effective for “soil drying”.
- The large majority of the decrease in moisture content and the increase in OMC occur within the first 4 hours. This puts question to the common practice of requiring a 24-hour or more mellowing period followed by a second mixing when the lime is thoroughly mixed into the soil in the initial mixing process and soil drying is the goal.

| TABLE 3  | Amount of 24-Hour Change in Soil Moisture and OMC That Occurs in the First 4 hours |
|-----------|----------------------------------|-------------------------------|-----------------|-----------------|
| Soil PI = 7 | Soil PI = 22 | Soil PI = 26 | Soil PI = 37 |
| 4% High Cal Quicklime | 74% | 78% | 100% | 98% |
| 4% Dolomitic Quicklime | 83% | 74% | 100% | 86% |
| 4% Hydrated Lime | 80% | 75% | 91% | 92% |
| 4% Hi Cal LKD | 63% | 69% | 95% | 86% |
| 4% Dolomitic LKD | 87% | 58% | 100% | 75% |
For the medium plasticity soils (PI = 22 and PI = 26):

- Quicklime – both high calcium and dolomitic – was slightly more effective than hydrated lime and both LKDs for soil drying. The combined effect of decreasing the soil moisture content and increasing the OMC was 1-2 percentage points greater with quicklime than with LKD or hydrate lime. This was noted at both 4 hours and 24 hours after initial mixing.

Upon second mixing at 24 hours after initial mixing:

- High calcium quicklime and dolomitic quicklime were equally effective for soil drying of the medium plasticity soils (PI = 22 and PI = 26).
- High calcium quicklime was slightly more effective than dolomitic quicklime for soil drying of the lower plasticity soil (PI = 7) and the higher plasticity soil (PI = 37).
- High calcium LKD was slightly more effective than dolomitic LKD for some soils. High calcium LKD “dried” the soil by about one percentage point more than dolomitic LKD in three of the four soils that were tested.

REFERENCES