D-Lab I Final Report:
Zeolite Beads for Seed Saving in Northern Thailand

Karina Lundahl, Sarah Sahlaney, Julia Shuck

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I. Executive Summary

This report examines the use of zeolite beads for seed saving in Chiang Mai province, Northern Thailand. It assesses the viability of using zeolite at a seed bank owned by the Educational Concerns For Hunger Organization (ECHO) that is preserving indigenous crop varieties in Mae Ai. This report also assesses whether zeolite is a viable technology for hill tribes in the region. The importance of informal indigenous seed systems in the hill tribe villages is discussed in terms of rural agroecosystem biodiversity, cultural significance, and economic support. Then a methodology is employed for comparing zeolite beads to other seed drying technology that may commonly be used in the region.

Zeolite is a naturally occurring clay that has been used for decades as an adsorbent for other purposes. But research has recently established that zeolite is also effective at drying seeds, a requirement for long-term storage. Zeolite drying beads are desiccants that adsorb water and can be used indefinitely through "recharging," or heating to release moisture. This study compares zeolite to other desiccants, silica and charcoal. While desiccants are an ideal technology smallholder farmers and seed banks often use non-desiccant technologies as they are less expensive and more readily available. However, these technologies tend to be less effective. Non-desiccant technologies assessed include: sun drying, solar drying and oven drying.

The methodology of this study attempts to analyze zeolite technology use through the four lenses of sustainable development as defined by D-Lab: technical, financial, social, and environmental. Subsequently, this study analyzed cost, technical efficiency, and environmental, health, and labor impacts of zeolite, silica, charcoal, oven drying, and sun drying. As a result, this study combines both quantitative analysis from the technical and financial lenses, and qualitative analyses from the social and environmental lens. These qualitative factors were highly significant in the study's findings and recommendations.

There were several significant findings associated with this study. First, the study established that while zeolite has high capital costs, its levelized costs are comparable with similar technologies such as ovens and silica. Zeolite is also highly efficient; it achieves the lowest base moisture content of all of the aforementioned technologies. Subsequently, Zeolite has an ideal cost-to-effectiveness ratio. Finally, the study found that zeolite demonstrates a high qualitative rating, particularly when that rating is weighted in favor of ECHO's interests and smallholder farmers' interests. As a result of these findings, it is clear that compared to other technologies, zeolite is relatively efficient, cost effective, and has valuable qualitative characteristics.

Given these findings, it is recommended that ECHO explore zeolite use for seed drying and storage. It may be particularly useful for long-term storage of indigenous germplasm. For use by smallholder farmers, it is recommended that a participatory sociocultural study be conducted to assess the need and desire for a new drying technology. For next steps by D-Lab, the exploration of alternate recharging technologies is suggested as a solution for reducing capital costs and increasing accessibility to the technology in developing areas that do not have reliable access to electricity.

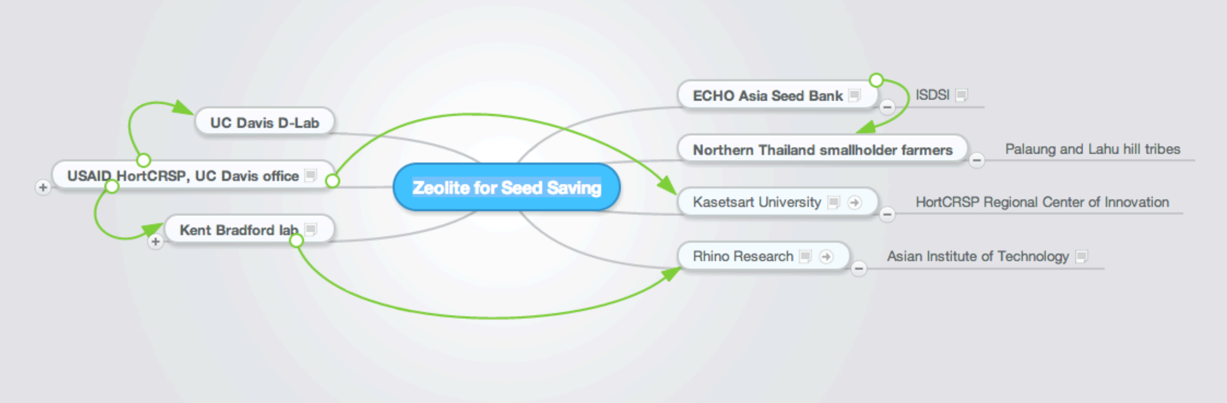
II. Introduction

i. Stakeholders

This report focuses on the use of zeolite for seed saving by two primary stakeholders in the Chiang Mai region of Northern Thailand: a seed bank in Mae Ai owned by the Educational Concerns For Hunger Organization's (ECHO) Asia Regional Office, and smallholder farmers in Chiang Mai and Chiang Rai, the Palaung and Lahu hill tribes.

Several interconnected parties (some of which are represented below in Figure 1) are currently researching the use of zeolite for seed saving. Professor Kent Bradford at the University of California, Davis (UC Davis) is the Principle Investigator on research funded by the United States Agency for International Development's Horticulture Collaborative Research Support Program (USAID HortCRSP) investigating the use of zeolite for seed saving in tropical climates. In that research, Bradford's lab is collaborating with zeolite producer Rhino Research and the Asian Institute of Technology (who are conducting a formal market analysis for zeolite), both located in Thailand. Not only does this report build on their work, but ECHO, Professor Bradford's lab, the USAID HortCRSP UC Davis office, and Rhino Research have all contributed essential information to this study in order to make it possible.

Figure 1. Map of Stakeholder Connections



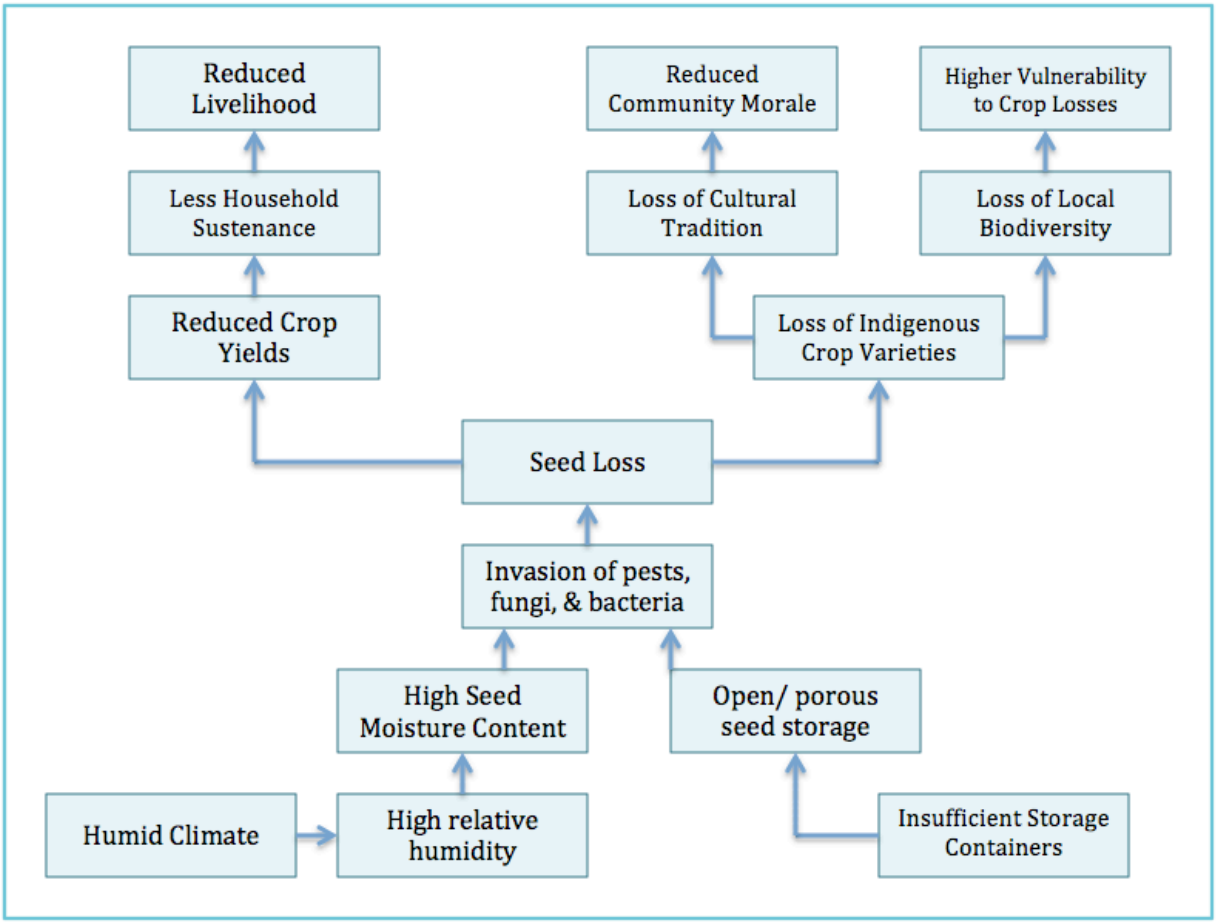
ii. Zeolite

While using zeolite, a naturally occurring clay, as an adsorbent or drying mechanism is not new, applying it to seed drying is novel. In recent years, Rhino Research has been researching alternative uses for zeolite. Their research has found that it is effective in drying seeds, herbs, fruits and vegetables, as well as preserving DNA (Bello 2013; Hansen 2013).

iii. Problem definition

Currently, up to 45.6% of seeds in Northern Thailand hill tribe communities are lost to pests, fungi, and bacteria – threatening biodiversity and the cultural tradition of seed saving (Bates, Bicksler et al. 2011). To address concerns of biodiversity loss, we will assess the financial viability of an effective desiccant technology, zeolite beads, for drying and storage of indigenous seed for our partner organization, ECHO's, seed bank in Mae Ai. As a possibility for strengthening cultural tradition, we will also assess the sociocultural and economic opportunities and barriers for zeolite adoption in hill tribe seed saving practices.

Figure 2. Problem tree representing issues addressed



III. Background

i. Why save seeds?

a. Biodiversity and sociocultural significance

ECHO has established a seed bank in Mae Ai to preserve indigenous seed varieties and supply regionally appropriate crops to local NGOs working with smallholder farmers in the area. In a recent report published by ECHO, the importance of informal seed saving and sharing systems in the Chiang Mai and Chiang Rai indigenous hill tribe communities was emphasized both for biodiversity and sociocultural significance.

Driven by violence, revolution, or uprisings, many in the hill tribe communities have migrated to the area from Myanmar, China and Laos. As a result, their seed saving practices reflect their experiences of migration, and remain a significant cultural aspect of the tribes' histories, narratives, and identities. Informal seed sharing is widespread and well established. For example, when a household in the community faces hardship, and is without viable seeds, it is customary for them to request and receive neighbors' seed varieties without owing money or goods in exchange (Bates, Bicksler et al. 2011).

Historically, the indigenous vegetable seed sector has been dependent on farmer saved seeds (Nath, Papademetriou et al. 1999). And while ECHO's findings support the continued importance of these networks for biodiversity in rural agroecosystems, they also point to weaknesses, such as the lack of a formal network of seed keepers, that indicate the need for further formalized support of informal seed systems.

b. Economic significance – Thailand

These informal seed saving networks are also economically beneficial, as hill tribe communities face challenges of poverty that are common throughout rural populations in Thailand. The annual income for hill tribe families is approximately 28,229 baht or $941 USD, one-fifth the national average of 141,480 baht or $4,716 USD (Bates, Bicksler et al. 2011). The communities also face limited access to education, but have some infrastructure established (roads and electricity), as is common throughout rural areas in Thailand. The majority tribe in these communities is the Palaung, and the minority tribes are Lahu. Although this racial distinction is present, wealth stratification divides communities more than race. ECHO's report indicated that farmers are more willing to ask someone who is from a different ethnic group for seed than someone from a different economic stratum.

Country-wide, 90 percent of the poor in Thailand live in rural areas, and most have no formal land ownership or secure land tenure (Mundlak, Larson et al. 2004). A case study by Ozturk (2009) cites that people who sold their land but maintained farming practices became tenants or worked on other farmland outside the village. Without land ownership, the tenant farmers faced major financial challenges. Significantly, although informal village borrowing and lending exist and are built on principles of reciprocity and trust (similar to the informal seed exchange in the Palaung and Lahu tribes), it occurs through a small village fund. Villagers stated that the fund only provided small amounts that did not allow for long-term investments. People's lack of land ownership stripped them of their ability to offer collateral if they were in need of a larger informal loan from agricultural middlemen (a process that is common, but also carries high interest rates).

As was observed by ECHO in the Palaung and Lahu tribes, wealth stratification seems to create both cultural and financial barriers. Not only is it intuitive that those with more income and capital would make more economic decisions in a capitalist economy such as Thailand's, Farrelly, Reynolds et al. also suggest a root for the deeper cultural influence dividing socioeconomic strata. They identify a "residual aristocratic order" reminiscent of the previous monarchy "where royalty and nobility customarily set standards for deportment, procedure, taste and aesthetics" (2011).

c.Economic significance – Worldwide

Worldwide, there are several reasons that NGOs such as USAID HortCRSP and Kew Royal Botanical Gardens, an educational gardening center that works with third-world farmers, encourage seed saving technologies. One of these reasons is that seed saving practices, particularly those that use technology to dry seeds, have potential long-term economic benefits. When farmers save seed in a way that effectively lowers moisture content within the seed, they have access to several economic opportunities.

First, effective seed drying increases the market value of seeds. When farmers produce seed, they either keep it for themselves to plant later or trade/sell it to other farmers. In the latter situation, drying allows farmers to effectively add value to the seeds; they last longer and will demonstrate higher yields (International Rice Research Institute, 2009). There are a few assumptions associated with this general prediction. First, there must be differentiation in the seed market based on quality levels; if farmers are not willing or able to pay for higher quality seeds, there is little to no economic benefit from drying. Second, farmers must have access to seed markets (International Rice Research Institute, 2009).

Seed drying technology also secures economic benefits by minimizing weather risks. Farmers who use sun-drying techniques are vulnerable to relative humidity, changes in temperature, and rain. NGOs have begun to promote seed-saving technologies in an effort to make farmers more risk-secure. Certain seed drying and saving technologies control for relative humidity and ensure that seeds are protected from losses due to weather. Minimizing risk for smallholders is therefore a huge potential economic benefit associated with seed saving technologies. (International Rice Research Institute, 2009)

Finally, seed drying allows farmers to process more grain within a time frame. NGOs tend to promote seed-drying and saving technologies because it can increase the scale of farmers' production. Drying and saving technologies allow farmers to save more seeds more effectively. The increase in seed storage subsequently allows farmers to plant more viable seeds and attain higher yields. Alternatively, farmers can sell more viable seeds at a higher value. Either of these options would theoretically result in a higher profit for the seed-saving farmer (International Rice Research Institute, 2009)

ii. How seeds are saved

a. Seed drying in tropical climates

Seed drying refers to the process of reducing heat and moisture from seeds (Liu, 1999). "The main objective of storing grain in a proper way is to maintain, through the whole storage period, the biological, chemical and physical characteristics that the grain possessed immediately after harvest (Silva, 1999)." Similar harvesting, handling, drying and storing techniques yield different results depending on local climate.

"Much of the tropical region is characterized by climates that makes it unsafe to store grains. High temperatures and relative humidity predominate over prolonged periods of time, thus increasing the potential for deterioration due to insects, birds, molds and rodents. Even in the best-constructed and best-managed facilities, storing grain in the tropics is a very difficult task (Silva, 1999)." The biggest issue in the tropics is the moisture content of seed, which increases respiration, generating heat and a favorable environment for insects and molds, two of the largest culprits in storage losses in developing countries (Silva, 1999). Figure 3 depicts the challenges faced in seed storage at different temperatures, relative humidities and seed moisture contents. The blue box indicates the ideal seed moisture content zone for medium to long-term storage.

Figure 3. Risks associated with seed storage in varying relative humidity and temperature conditions

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Relative humidity is defined as the amount of water vapor present in air. Relative humidity is interdependent on temperature and inversely related to it. As temperature rises, relative humidity decreases (Liu, 1999; Devereau, 2002). Seed moisture content, or internally held water, is in equilibrium with relative humidity and temperature. This balance varies between seed species (Liu 1999).

Water is fundamental for many chemical and biological reactions so seeds with more water will be more susceptible to deterioration than seeds with a lower moisture content (Devereau, 2002). According to Pedro Bello (2013), the more oil a seed has, the less water it can hold, and therefore, seeds with more oil and less water deteriorate slower and dry faster as there is less water to lose through diffusion of moisture between the seed and the air.

While cereal grains and legumes have a moisture content of 35-45% at harvest, they need to be stored at 10-14% moisture content to prevent deterioration. While crops are ideally harvested during dry periods, irrigation, other agricultural practices and early maturing seed varieties have increased the need for artificial drying (Boxall, 2002).

b. Seed drying technologies

This study's methodology seeks to compare the related costs, effectiveness, and qualitative factors of six different drying technologies. It is first necessary, however, to briefly explain each of these technologies and how they are used in-country. These technologies are split into two general groupings: desiccants and non-desiccants.

Desiccants:

Desiccant technology works by adsorbing moisture in the surrounding air; adsorption occurs when moisture is tightly held at a molecular level versus absorption where moisture is dissolved. When seeds and desiccants are put into a hermetic container, the seeds release moisture until the seed moisture and the relative humidity of air in the container are balanced. The desiccant then adsorbs the moisture in the air, causing the seeds to continue losing moisture until the seed, relative humidity in the air, and the desiccant have reached a moisture balance.

When assessing the effectiveness of zeolite, it is most easy to compare desiccant technologies because they adsorb moisture similarly. The three desiccants this study examines are zeolite, silica, and charcoal.

Silica draws the most direct comparisons to zeolite beads, as the two technologies are used in similar ways. Silica gel beads are added to seeds and both are stored in an airtight container for a specified amount of time. The beads are then removed and, if the beads are not yet dry enough, are recharged in an oven, cooled, and then mixed back in with the seeds.

When compared to zeolite, silica has a few differing characteristics. First, silica's moisture adsorption rate decreases rapidly. At 20% relative humidity, silica cannot adsorb moisture after one day. In comparison, zeolite can continue to adsorb moisture from seeds at increasingly marginal rates for at least ten days. Furthermore, silica beads cannot reduce the relative humidity in an airtight container beyond a threshold of approximately 29% (Van Asbruck, 2009). In comparison, zeolite beads can create a relative humidity in an airtight container of approximately 5% (Van Asbruck, 2009). The difference in these potential relative humidities suggests that, of the two technologies, zeolite is much more effective in creating a dry environment in an airtight container. There are other elements in the silica-zeolite debate as well. Significantly, silica gel beads are carcinogenic. Environmentally, silica can contaminate water if it is not disposed of properly. Further comparisons of financial, technical, and environmental factors are in the methodology section of this report.

Charcoal is another alternative to zeolite. Like zeolite and silica, charcoal is a desiccant that is combined with and draws moisture from seeds. Charcoal must first be heated and dried. This can be done in an oven; however, according to Kew Royal Botanical Gardens, charcoal is mostly dried in the sun in developing countries (Kew Royal Botanical, 2013). Seeds are then mixed with the sun-dried charcoal. The lowest base moisture content of seeds mixed with charcoal is approximately 12% (Kew Royal Botanical, 2013). Charcoal costs are very low compared to zeolite.

However, charcoal has qualitative characteristics that make it a less-than-ideal desiccant for seed drying. First, it has negative and unsustainable environmental effects, as it can lead to deforestation and air pollution. Charcoal creation may also be dangerous to lung health and is relatively labor intensive. Finally, although charcoal can reduce seed moisture content a great deal, it is ultimately not as effective in reducing seed moisture content as either silica or zeolite and thus does not effectively preserve seed viability. Given these considerations, charcoal may be a more appropriate technology for lower value seeds grown by smallholder farmers. Low-value seeds do not necessarily need to be dried to such low moisture contents, and farmers who do not have access to stoves can dry charcoal in the sun.

Non-Desiccants:

In addition to desiccants, there are several non-desiccant technologies that may be appropriate for seed drying in Thailand. These include sun drying, solar drying and oven drying.

The most common drying technique in the world is sun drying, according the FAO (1985). This is an inexpensive method, which ideally, but not always, is done on top of tarpaulins to reduce mixing the seeds with debris (i.e. dirt and small stones). While sun drying requires little to no money, it has the greatest risk of damaging seeds. The harsh sun can cause seeds to crack, discolor and decrease their rate of germination while still not reaching the base moisture content level needed for storage due to relative humidity (Liu

1999; Boxall 2002; Muhlbauer 1992). The FAO suggests that farmers place their seeds in the shade instead of direct sunlight to dry, but this is not commonly practiced.

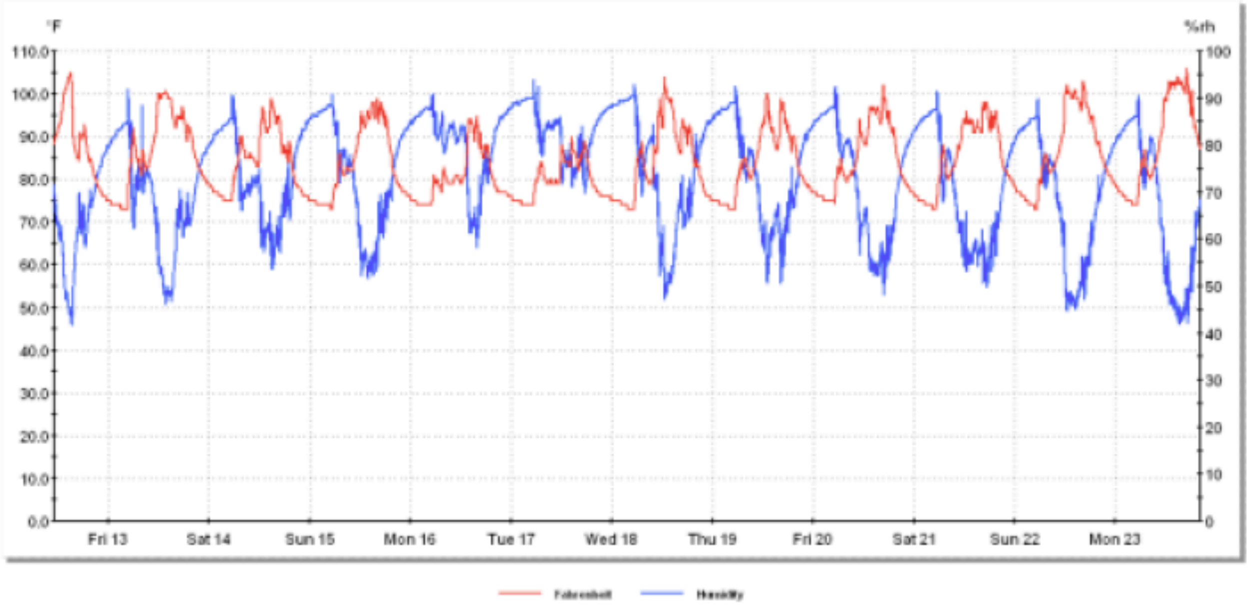
The potential for solar drying seeds in tropical areas has been assessed for many years. The major issue with this endeavor continues to be the high relative humidity of Thailand (Silva 1999). In order to increase the likelihood of use, a basic solar dryer that does not need electricity or motors was assessed. This solar dryer is made of 2 x 4's and thick, clear plastic. The design of this technology allows natural wind to flow past the seeds, decreasing the time needed to dry (Boxall 2002). However, this method achieves limited lowest base moisture content and requires mending every few years. Solar dryers similar to this have been suggested for use in Thailand for decades but have not been adopted on a large scale.

Ovens are commonly used to dry seeds by those with greater access to financial and capital resources, such as our partner ECHO and other seed saving institutions. Seeds are spread thinly on a baking sheet and put in an oven at approximately 100-200 degrees Fahrenheit for several hours at a time, depending on the size of the seed (Kew Royal Botanical Institute). Oven drying can achieve a relatively low base moisture content in seeds and is also relatively cost effective. However, oven drying does not preserve seed viability well; seeds may easily become overheated and subsequently non-viable. Furthermore, oven drying can also have high energy costs and subsequently is not environmentally sustainable.

iii. Current practices in Thailand

Currently, ECHO sun dries seeds before completing the drying process in an oven. They then vacuum seal and/or store their seeds in a cool storage room that requires electricity. Hill tribe farmers dry their seeds in the sun, exposing seeds to Thailand's average relative humidity of 80%. They then store seeds either in a basket above the household fire (where they indicate the smoke repels potential pests) or by putting seeds in a plastic bag that is hung on a wall in the house (Bates, Bicksler et al. 2011). Figure 4 (below) shows ECHO's measurement of temperature and relative humidity above the fire in a typical household. Comparing community seed to commercial sources, ECHO found seed viability to be generally similar.

Figure 4. Temperature and relative humidity above typical hill tribe household fire



The red line indicates temperature in Fahrenheit, and the blue line indicates percent humidity. Measurements were taken between May 11 and May 23, 2011(Bates, Bicksler et al. 2011)

IV. Methodology

The methodology of this study aims to address the four lenses of sustainable development as defined by D-Lab (financial, social, environmental, and technical). Our approach poses three main questions. First, how do the costs of zeolite beads compare to the costs of other technologies? Second, how do the costs of zeolite technology and other drying technologies line up with their overall effectiveness in drying seeds? Finally, how is it possible to compare technology across the more qualitative factors that truly differentiate these technologies?

In order to address the financial lens, the analysis collected data on capital costs, levelized costs, and lowest base moisture content for zeolite, silica, charcoal, oven drying, solar drying, and sun drying. Levelized costs were factored over two years. In order to determine how oven costs affected levelized costs, the methodology included a set of levelized costs with ovens and a set without. With respect to capital costs, we collected cost data on desiccant technology (silica, charcoal, or zeolite), storage containers, ovens, baking trays and containers, and tarpaulins (see Figure 5 below). (Note: costs of appropriate storage are not included in this analysis; capital costs for zeolite and silica both contain containers because these are an integral part of the drying process.)

Figure 5. Inputs Factored Into Levelized and Capital Costs

Technology	Levelized Costs Inputs	Capital Cost Inputs
Silica	Silica Beads, Airtight Containers, Baking Containers, Energy Costs	Silica Beads, Airtight Containers, Oven, Baking Containers
Charcoal	Charcoal, Tarpaulin	Charcoal, Tarpaulin
Zeolite	Zeolite Beads, Airtight Containers, Baking Containers, Energy Costs	Zeolite Beads, Airtight Containers, Oven, Baking Containers
Sun Drying	Tarpaulin	Tarpaulin
Oven Drying	Energy Costs, Baking Sheets	Oven, Baking Sheets

In order to interpret technology use through the technical lens, this analysis considered effectiveness measures. The methodology considered both relative humidity (RH) and moisture content (MC) for each of the listed technologies. While there is significant data for each of these measures, it is difficult to compare how each technology reduces moisture content and relative humidity because data on different technologies may differ with respect to starting RH or MC. Because there is no standardized starting MC or RH, it is difficult to determine how long each technology will take to dry for a given drying technology.

However, there is widespread data on lowest base moisture content (lbMC), or the lowest moisture content that the technology can attain in seeds. This measure compares across technologies which technology can most effectively dry seeds. Subsequently, data was collected on lbMC for each of the six technologies above. After examining each technology's lbMC, lbMC was matched with levelized cost. In essence, this comparison provides a rough cost-to-effectiveness ratio. This ratio, discussed in the analysis section below, demonstrates how much different technologies would cost the client versus the quality of drying with each technology. The ideal technology would demonstrate a low levelized cost as well as low lbMC.

Finally, research suggests that there are several qualitative factors that incorporate the social and environmental lens. These qualitative factors make zeolite highly valuable, but are difficult to compare in a standardized way. In order to compare the qualitative elements of different technologies, a cumulative qualitative assessment score was created. This process involved three steps. First, several qualitative factors were selected. These included health, environment, labor, and seed viability. Then, based on research, each technology was given a score for each of the factors mentioned above. Finally, scores were averaged to get the cumulative qualitative assessment score. Weighted scores were also provided; ECHO's weighted average considers seed viability as the most important factor, while farmers' weighted average focuses more on health and labor. While this methodology is subjective, it provides a way of comparing, ranking, and scoring qualitative factors that are important aspects of each drying technology. The table of respective scores is included in Figure 6 below.

Figure 6. Qualitative ranking of technologies

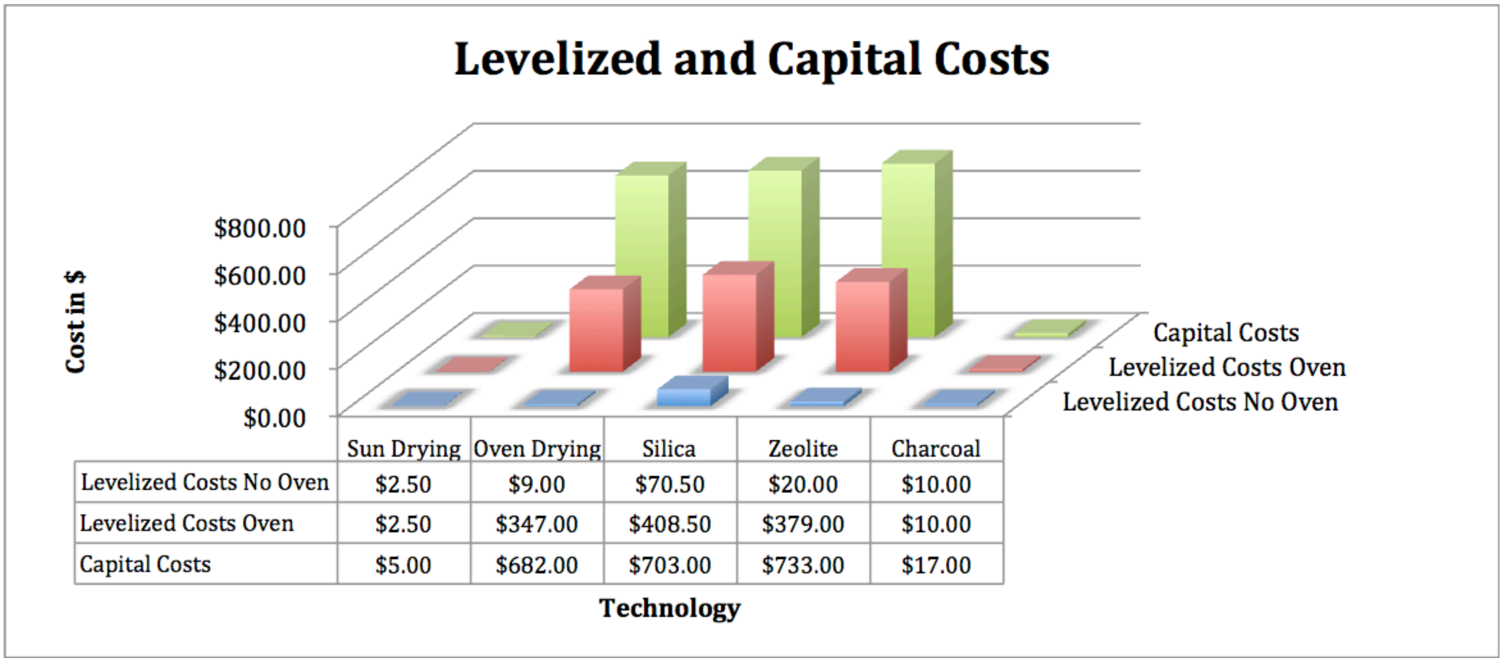
Technology	Health	Environment	Labor	Seed Viability	Average Score
Silica	1	1	3	4	2.5
Charcoal	2	1	1	2	1.5
Zeolite	4	3	4	4	3.75
Sun-Dry	4	4	4	1	3.25
Oven	4	3	4	1	3

V. Results

i. Discussion

Based on our methodology, we set out to determine how cost, effectiveness, and qualitative factors compare among silica, zeolite, charcoal, sun drying, and oven drying. Our analysis of these areas revealed three significant findings. First, it is clear that zeolite is relatively cost-comparable to similar technologies. Capital costs for zeolite are the highest of any drying technology. However, when these costs are levelized over two years, zeolite is not the most expensive drying technology; it is less than silica and only slightly more expensive than ovens. The reason for this is zeolite's longevity. Silica must be recharged frequently, and becomes less and less effective after each recharge. After 4 to 5 recharges, it becomes ineffective. Subsequently, over a two-year period silica must be replaced several times, thus bringing the overall cost of silica up. If silica costs approximately $10 per kg and must be replaced five times over two years (a conservative estimate) it will cost $50. Zeolite, though initially more expensive at $40 per kg, can be recharged indefinitely and does not need to be replaced. Therefore, the levelized cost of zeolite is lower than that of silica (see Figure 7 below). If the cost is levelized over additional years, zeolite will be even more cost-effective compared to silica.

Figure 7. Capital and Levelized Costs



	Sun Drying	Oven Drying	Silica	Zeolite	Charcoal
Levelized Costs No Oven	$2.50	$9.00	$70.50	$20.00	$10.00
Levelized Costs Oven	$2.50	$347.00	$408.50	$379.00	$10.00
Capital Costs	$5.00	$682.00	$703.00	$733.00	$17.00

Second, this study compared levelized cost against drying effectiveness. Zeolite technology is the most effective at drying; it yields a lbMC much lower than ovens, silica, charcoal, or sun drying. As mentioned above, an ideal seed-drying technology will demonstrate both a low lbMC and a low levelized cost. Compared to zeolite, charcoal and sun drying have extremely low levelized costs, but very high lbMCs. Silica has high levelized costs and relatively low lbMC. The two technologies that show ideal cost-to-effectiveness ratios, however, are ovens and zeolite. These technologies both demonstrate low lbMC as well as relatively low levelized costs (see Figure 8).

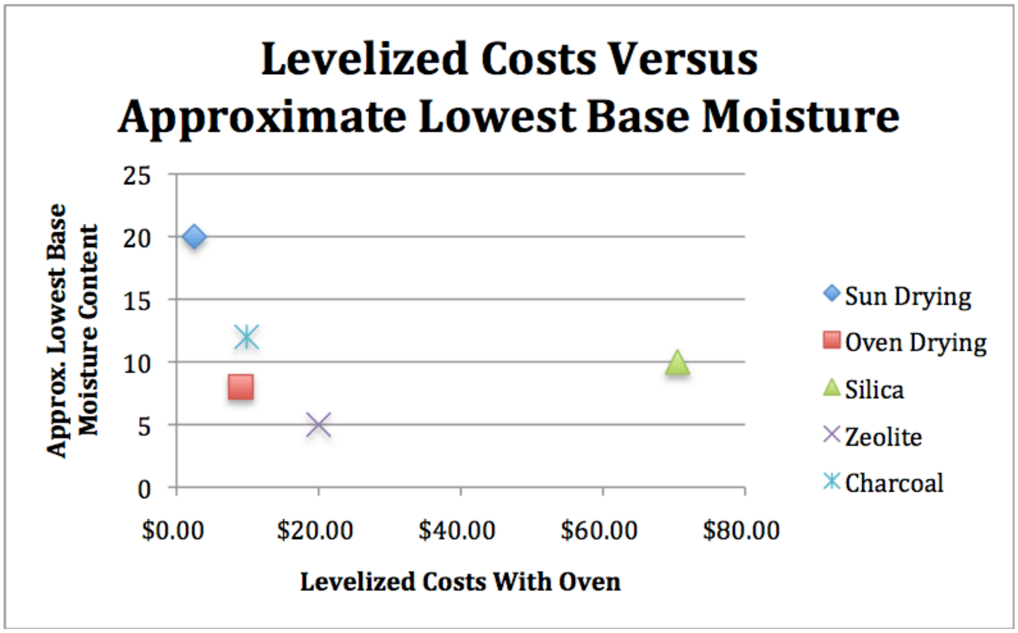
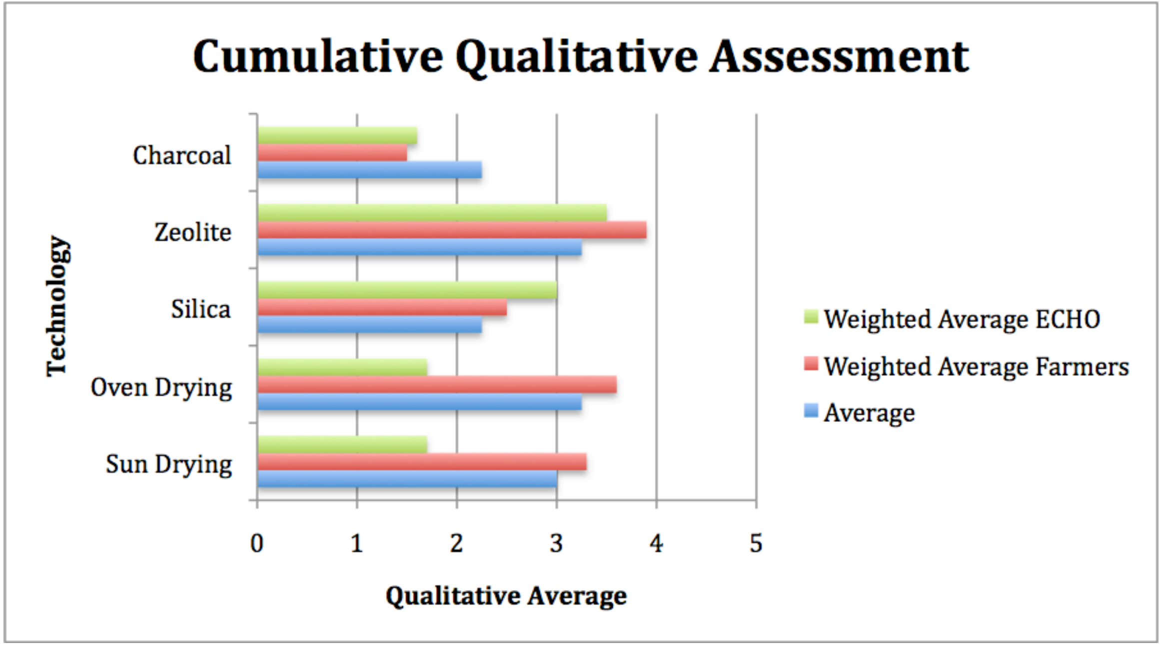


Figure 8. Levelized Costs Versus Lowest Base Moisture Content

Given these analyses, it would appear that zeolite and oven drying are both reasonable considerations with respect to cost and drying efficiency. However, as mentioned above, there are a number of qualitative factors that are critical in this comparison as well. Each of the technologies mentioned above has effects on environment, health, labor, and seed viability. When these effects were coded, added together, and averaged, it became clear that zeolite had the highest qualitative cumulative assessment score for both ECHO's uses and farmers' uses. One particularly interesting finding is the score that zeolite demonstrated over ovens, especially in the weighted average for ECHO. This is because ECHO's weighted average stressed seed viability. Zeolite is highly effective in preserving seed viability, while oven drying is much more likely to harm seeds in the drying process. Due to this factor, zeolite's qualitative ranking was much higher than oven drying's, which may be a crucial finding for ECHO to consider (see Figure 9).

Figure 9. Qualitative Cumulative Assessment



ii. **Remaining Questions**

Financially, is this technology affordable for smallholder farmers? Farmers in Thailand participate in informal and formal seed markets, and the incomes of smallholder farmers vary depending on location. For a given farmer in Thailand, is the cost of zeolite within their reach and are they using current inputs that could be used as a comparison? This report focused on drying seeds as they are assumed to have a higher value per kilogram than major commodity grains such as corn or soybeans, but this assumption needs to be researched further.

Socially, do smallholder farmers want this technology? Actual need and perceived need are not always in alignment. Determining to what degree farmers find zeolite drying beads necessary and feasible needs attention. Also, will zeolite beads fit into their current drying practices? Does using zeolite drying beads add more work or go against a strongly held belief about seed drying that may render this drying tool useless from their perspective?

Technologically, will zeolite remain as effective in the field? Zeolite drying beads have been thoroughly tested and used in laboratory settings, but as was noted by Peetembar Dahal in Professor Bradford's lab, farmer cooperatives in Nepal have not been able to recharge the beads by baking in an oven as had been previously assumed.

Zeolite drying beads were not evaluated closely for environmental impacts in this project. While there were not any glaring environmental issues with the use of the drying beads, there may be hidden impacts that need to be addressed.

VI. Recommendations

i. ECHO

Given the high efficacy of zeolite and low levelized cost compared to oven drying, it is recommended that ECHO explore zeolite beads as a possible technology for seed saving. However, as Professor Bradford has suggested (personal interview, March 8, 2013), if capital costs remain a deterring factor, ECHO may also want to consider zeolite for specialized use in storing indigenous germplasm. Because zeolite is capable of gently lowering seed moisture content below the lowest moisture content possible with oven drying, it may be particularly useful for long-term storage of varieties. One could employ a tiered method, first drying seed with an oven, then using zeolite to bring the final moisture content as low as possible, extending the life of the seed.

ii. Smallholder Farmers

Given the remaining questions related to the hill tribes and other smallholder farmers in Thailand, an in-country sociocultural study is also recommended. To fully assess the need for zeolite, one should conduct a survey of local best practices in seed drying and storage, identify areas for improvement, and assess whether the introduction of a new technology is the most effective solution. The sociocultural study should also include smallholder farmers as participatory members, gauging community need and desire for the incorporation of zeolite and possible changes in practice it may bring.

If it is determined that zeolite is most effective, one feasible market option may be to introduce zeolite beads into community lending structures that already exist in hill tribe communities and other rural villages. Cultural barriers may prevent sales and trade between impoverished rural communities and wealthier landowners and farmers. However, separate introduction into both markets may alleviate what might otherwise be unrealistic cost at small scale. Although the electricity needed for recharging zeolite beads poses a problem in other developing countries, the well-developed infrastructure of Thailand, even in poorer rural communities, does not appear to present a problem.

iii. Other studies to review

A full market analysis for zeolite is being conducted by the Asian Institute of Technology in Thailand. In considering the broader financial viability of zeolite for seed drying, one should review this study for market barriers and/or opportunities for zeolite.

As mentioned above, another important consideration for zeolite in humid climates will be its degree of retained efficacy when used in the field, outside of controlled environments. Professor Bradford's lab is conducting long-term field experiments in Nepal measuring relative humidity within storage containers with seed dried by zeolite. In considering the long-term practicality of smallholder farmers using zeolite in developing countries, one should review these findings closely.

iv. D-Lab II: Next Steps

It is recommended that D-Lab II assess two areas of interest: zeolite bead recharging techniques, and the efficacy of various storage options. Both Rhino Research in Thailand and Professor Bradford's lab at UC Davis are looking into alternative bead recharging technologies, which could be field-tested and/or amended by D-Lab II students.

Suggested storage containers to assess include:
1. CIMMYT hermetic bags vs. plastic bags vs. open jute bag
2. Sealed plastic containers vs. old/non-sealed containers
3. Vacuum sealing

For initial background readings concerning drying and storing seeds, a suggested reading list has been created for D-Lab II students to review (see Appendix).

VII. Bibliography

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VIII. Appendix: Suggested Readings for Seed Drying and Storage

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This is a study done on the impact of three different storage methods on chickpeas in the same environment, which was indicative of local storage versus laboratory storage. The book of these conference proceedings can be found in the UC Davis Peter Shields Library.