8-17-2016

A Quantitative Analysis Of Hugelkultur And Its Potential Application On Karst Rocky Desertified Areas In China

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A QUANTITATIVE ANALYSIS OF HUGELKULTUR AND ITS POTENTIAL APPLICATION ON KARST ROCKY DESERTIFIED AREAS IN CHINA

A Capstone Experience/Thesis Project

Presented in Partial Fulfillment of the Requirements for

the Degree Bachelor of Biology with

Honors College Graduate Distinction at Western Kentucky University

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Western Kentucky University
2016

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ABSTRACT

A type of environmental degradation, karst rocky desertification (KRD) refers to areas where the soil loss exposes the bedrock and reduces the land's ability to sustain life and is particularly widespread through the vast karst area of rural southwest China. Hugelkultur is a permaculture method that harnesses the wood decomposition process by burying logs beneath soil. We proposed that hugel beds will demonstrate a higher water holding capacity and enhance soil development, in a way that may show promise as a potential method to help alleviate problems of KRD. Soil samples were taken from hugel plots, non-hugel plots, and KRD-like areas around Bowling Green, Kentucky to determine respective moisture content and project the amount of soil water potentially held in a one-hectare field. Findings show hugels to demonstrate higher water holding capacity meaning they have potential implications for future productivity of agricultural in areas affected by KRD.

Keywords: hugelkultur, karst rocky desertification, permaculture, China, sustainable agriculture

Dedicated to
my wonderfully supportive parents who let me do my thing.

ACKNOWLEDGEMENTS

I would like to express my deep gratitude to Dr. Albert Meier for allowing a lost freshman into his lab. I have become much more of a scientist and explorer under your guidance. Thank you for reminding me to always challenge myself and those around me.

Deep thanks is also due to Dr. Chris Groves without whom I would have never learned of karst rocky desertification and would have missed out on many incredible opportunities. Thank you for continuous support and encouragement.

Many thanks to Tim Kercheville for his valuable expertise on hugelkultur. I would also like to thank the Office of Scholar Development for helping me develop and reach for my dreams; Project Grow and other volunteers for their invaluable labor; Erika Brady and the Universalist Unitarian Church of Bowling Green for allowing me to test their hugels.

I would like to acknowledge the financial support from the Barry Goldwater Scholarship, WKU FUSE Grant, WKU Sisterhood Lifetime Experience Grant, WKU Green River Preserve.

Finally, thank you so much to the WKU Honors College for allowing me the opportunity to pursue my own research interests.

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FIELDS OF STUDY

Major Field: Biology

Minor Field: Agriculture

Chinese Flagship Program

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CHAPTER 1

INTRODUCTION

As an increasing number of social and scientific studies concerning the state of global food and water security emerge, global food security has become one of the forefront issues to be addressed by researchers and policy makers alike. Pressures created by rapid population growth, shifts in economic consumption and climate change threaten the framework of the global agricultural industry as demand increases and supplies dwindle. As a result of rising food and water prices, global financial and economic challenges arise and impoverished populations suffer the brunt of the impact of food insecurity (Conceicao & Mendoza, 2009).

According to a UN report on global agriculture development, world food demand is predicted to rapidly increase; moreover, the average diet is expected shift to be more dairy and meat heavy (Conceicao & Mendoza, 2009). Recent studies project that by 2050, in order to support its population, the world will need to produce 70-100% more food (Hall et al., 2009). Global cereal demand is expected to increase by 75%. Concurrent with increased demand for meat and dairy products, demand for animal feed will also increase (Conceicao & Mendoza, 2009). Moreover, as the demand for alternative biofuels increases, several types of high calorie food crops originally used exclusively for food are now being repurposed for energy. In addition to transitions in demand trends, challenges faced by suppliers compound the global food crisis. High drought frequency worldwide weakens the supply chain of staples such as wheat, maize, and rice. As a result of climate change in predominantly agricultural regions, not only has the amount of arable land available to support the world population decreased approximately 60% in the past 50 years, but crop productivity has been projected to decrease by 3% to 16% per hectare (Conceicao & Mendoza, 2009).

One of the most serious consequences linked to climate change is environmental desertification. Global desertification and dryland development have been identified as serious environmental problems. The impact of desertification on agricultural productivity, water availability, and biological diversity is of great concern to world leaders. Semi-synonymous with degradation, desertification carries with it stronger implications of aridity and bareness. When broken down, it literally means to become "desert-like." In 1992 the United Nation Convention to Combat Desertification defined desertification as “land degradation in arid, semi-arid, and dry subhumid areas resulting from various factors, including climatic variations and human activities” (Reynold, et al., 2007). As a result of soil erosion and vegetation loss, the area’s capability to sustain life is diminished. Although climate change influences rates of degradation, there is an even stronger correlation with direct human activities.

<u>Desertification</u>

Current research focuses on the interactions between several biophysical and anthropological influences to assess degradation risk. According to a meta-analysis of land degradation studies, the most prominent indicators include “(i) rain seasonality affecting water erosion, water stress, and forest fires, (ii) slope gradient affecting water erosion, tillage erosion and water stress, and (iii) water scarcity soil salinization, water stress, and forest fires" (Kairis et al., 2014).

Drylands typically naturally have lower precipitation levels, leaving them more vulnerable to drought, and as climate change is projected to further reduce precipitation and increase temperatures globally, these desert-like conditions will only be exacerbated (Dami, Adensima, & Adeoya, 2010). Global climate change alters the temperature and precipitation, solar radiation levels, and wind strength, which can cause environmental degradation of drylands around the world. Anthropological abuse such as overgrazing, irrigation, and land mismanagement, also catalyze desertification.

Studies in the Chihuahuan Desert of North America have shown that the grazing patterns of large herds of cattle greatly influence the relationship between soil and plant composition. An area that has been heavily grazed for an extended period of time will sustain considerable grass loss and soil compaction, thus leading to reduced competitive potential of grasses against shrubs and lowered infiltration rates in soil (Schlesinger, et al., 1990). The impact of unsustainable irrigation methods has also been clearly demonstrated at both the Aral Sea and Ili River delta in Central Asia. In both of these locations, the growing demands of agricultural expansion and the burgeoning burden of human consumption have led to the increased irrigation of essential water sources, thus reducing water availability (Harriman, 2014; Starodubtsey & Truskavetskiy, 2011)

Clear-cutting, over tillage, and general de-vegetation remove the protection provided by root systems and leave soil more vulnerable to erosion.

The effects of desertification depend on the situation that caused them. In areas impacted by overgrazing from animal herds, grasses become less and less competitive and the soil is compacted. The compact soil decreases water infiltration and increases water runoff, thus promoting soil-nutrient level heterogeneity leaving some areas over fertilized and others devoid of nutrients. As a consequence, the vegetation composition shifts: shrubs outcompete the native grasses and areas of fertile soil become disconnected (i.e. only small patches of fertile soil surrounded unfertile soil) due to the positive feedback cycle created by the shrub's roots: the roots allow for more water infiltration, leading to higher soil moisture, and thus higher fertility (Schlesinger, et al., 1990). This compacted soil can also lead to an increase of erosion due to flooding as precipitation can no longer properly drain into the soil, causing greater runoff and preventing ecological recovery even in moist conditions.

Additionally, desertification caused by over irrigation or mismanaged irrigation systems can lead to soil salinization and dust storms. In most cases, the source streams for larger bodies of water are diverted to serve agricultural and public health purposes. As populations grow, more water is required to maintain these areas; therefore, more water is diverted away from the source. When areas where the water has a naturally high salinity are desertified--seas or salt marshes for example-- the receding waters will leave behind soils high in minerals. Then, as high winds blow through the desiccated area, those particles are picked up and carried in salt-dust cloud to locations up to 1,000 kilometers away (Semenov, 2011). The agricultural runoff and salt (sodium bicarbonate, sodium chloride, and sodium sulfate) aerosols will blow into neighboring vegetation and cropland, slowing or even preventing growth (Micklin & Aladin, 2008).

The most prominent manifestation of desertification is high volume soil erosion as it contributes to and defines the severity in all other symptoms. Damage from overgrazing and the impact of wind erosion both exemplify the feedback loops involved in desertification. Whether through clear-cutting, soil tillage or general over cultivation, the greatest contributor to increased soil erosion is destruction of vegetative cover. Without the protection provided by roots, the vulnerability of topsoil to erosion increases asstudies show that a plant cover of at least 50% is needed for adequate protection (Wu, 2011). Areas with greater than 75% vegetative cover, like those typically found in forested and agricultural areas, are not as impacted by soil erosion (Kairis et al., 2014).

The degree of desertification is a result of the interplay between many factors. Vegetation, water runoff, soil characteristics, climate, agricultural and land management, and social and institutional structures interact to fight soil erosion (Kairis et al., 2014). The disappearance of soil ultimately leads to land infertility, an outstanding and defining characteristic of desertification.

Karst Rocky Desertification

Desertification can be broken down into several categories contingent on the native characteristics of the degraded area and its environmental indicators (Kairis, et al., 2014). While the majority of desertification takes place in arid to semi-arid environments, areas adjacent to deserts, one specific type of desertification is an exception. Rocky desertification refers to areas where the soil has eroded away down to the point of exposing subsurface bedrock rock. In areas geologically dominated by karst rocky formations, this environmental phenomenon is referred to as karst rocky desertification (KRD).

Accounting for approximately 12% of the earth's surface, karst rock areas are typified by the presence of caves, sinkholes, fissures, and subsurface aquifers, a feature primarily precipitated by aqueous hydrogen-carbonate dissolution (Groves et al., 2002). Composed of soluble carbonate rock, primarily limestone though dolomite and gypsum are also relevant, karst landforms evolve through corrosive chemical interactions between calcium carbonate and hydrogen ions. Acidic rainwater, during its time in the atmosphere and as it percolates down through decaying organic matter in soil, gathers high amounts of CO_2, creating a weak carbonic acid. The weak acidic water dissolves through the carbonate rock and promotes dissolution of $CaCO_3$. As a result, karst terrains develop highly interconnected webs of subsurface fracture and pores that overtime can further dissolve into caves and aquifers (USGS, 2013).

The epikarst, or subcutaneous zone, is the topmost rock layer right below the soil. Highly weathered, porous and permeable, the epikarst acts in a water storage capcity in karst environments. Fissures and smaller fractures within the epikarst respectively allow water to infiltrate the karst and prevent it from percolating too quickly. By suspending water near the surface, the epikarst inhibits rapid discharge and sustains water through dry seasons (Williams, 2008). The epikarst can act like a “sponge” in the shallow bedrock that can get charged with water in the wet season, storing it into the drier winter seasons. When the soil and vegetation within the epikarst deteriorates and erodes away, any form of precipitation will immediately begin percolating down through the bedrock. Without the soil to hold water at the earth’s surface, plant and human populations face dry, desert-like conditions even as groundwater races beneath the surface thus lending relevance to the term desertification. In Guizhou, China, even though the annual rate of precipitation is 1000-1200 millimeters, this heavy rainfall can serve to exacerbate soil erosion while it leaks down into the groundwater, thus limiting the water available for vegetation and human use and consumption (Wang, Liu, & Zhang, 2004).

Just as with other areas of soil erosion, the severity and speed at which the surface soil and the epikarst disappears correlates with the slope gradient and slope aspect. Steeper, south-facing slopes are more vulnerable to erosion than their moderate, north-facing counterparts (Kairis et al., 2014).

Karst land areas are considered one of the most fragile ecosystems as a result of carbonate solubility and the overall susceptibility to soil erosion. KRD is not limited to arid environments, and affected areas are primarily concentrated in the sub-humid/humid karsts of southwestern China. One of the three largest continuous karst areas in the world, the southwestern China karst spans through parts of Guizhou, Guangxi, Yunnan, Hunan, Sichuan and Chongqing provinces in southwestern China. Exemplified by its stunning natural karst landforms, the towering and craggy karst formations serve as the archetype for karst development in humid tropic and subtropic climates and a world reference site for many types of karst formations including the pinnacle karst of Shilin in Yunnan and the cone and tower karst of Libo in Guilin (UNESCO World Heritage Centre, 2016).

Although well known for its pockets of rich, old growth forest and diverse ecosystems, in relation to the social and industrial development of rural China, this area is threatened by the development of KRD. Research conducted on the development and effects of KRD rely on remote sensing, ground surveys and statistical data to monitor the land degradation on a multi-scale and multi-temporal level (Zhang et al., 2014). The increase in threat has been linked to human impact (Xiong, et al., 2009; Wu et al., 2011). Studies using remote imaging systems like Landsat established the correlation between proximity to human activity and level of soil degradation by comparing images exemplifying spatial and temporal transitions. The extent of degradation varies with the degree of severity comparing the ratio between vegetative coverage and bedrock as an ecological indicator, ranging from light, moderate, to strong and extremely strong (Zhang et al., 2014; Kairis et al., 2014). Areas with over 80% vegetative coverage are said to have no KRD, and those with 9-10% are classified as areas of strong KRD (Li et al., 2009).

Studies examining the driving forces of KRD indicate that just as with the process of general desertification, it comes as a result of the interplay between a variety of biological, geological, and anthropological forces (Kairis et al., 2014). Early work on the influences on KRD development show that environmental factors like precipitation and temperature as well as topographic characteristic were the most significant influence in KRD development. However, although meteorological, topographical, and lithological factors still play a large part, the impact of human activity is now largely indicated as the premiere driving force of KRD (Xu et al., 2013). Southwestern China has a distinctive history of large-scale deforestation and slash and burn cultivation, both of which transformed the rural countryside, leaving it vulnerable to more ecological degradation (Wu J. , 2011).

The prevalence of poverty in the affected areas significantly influences the cycle of environmental degradation and KRD development. The 40% of the population residing within the southwestern China karst area live below the international poverty line (Cai et al., 2014). Increasing ecological pressure due to explosive population growth and the mismanaged development of agricultural plots on the already vulnerable soil on steep karst slopes has exacerbated the cycle postulated by Tang and Xia in 2001: poverty→ population growth→ environmental degradation→ more poverty (Tang & Xia, 2001). For example, in Guizhou Province, the poorest of China's 34 provinces, the land area is 97% mountain and hills, land formations that are considered more vulnerable to soil erosion (Wang et al., 2004). As the population in these areas grows at an annual rate of 14%, suitable, fertile agricultural land diminishes, forcing famers to expand into mountainous areas through deforestation, destruction of grasslands and overgrazing herds. As neither of these solutions lend themselves to peak production, the farmers are losing much of their time and land investments (Wang, Liu, & Zhang, 2004).

As desertification often results from positive feedback loops, current solutions focus on breaking the cycle of degradation. Strategies for managing desertification range from implementing anti-poverty measures through educational opportunities, developing agroforestry techniques, integrating pastoral and agricultural systems, and emphasizing native and economically profitable plants. The encouragement of nitrogen-fixing vegetation growth, terracing to control soil erosion, and other land protection regulations have been promoted such as the Grain for Green program (Wang et al., 2004; Kairis et al., 2014; Yang et al., 2013). Other rehabilitation programs have been successfully implemented including restricting hillsides from being used for grazing and firewood gathering to allow for successive ecological recovery and afforestation (Wang et al., 2004). However, although solutions are still being explored and some have been successful in rehabilitating small localities, a more comprehensive solution is needed to address the growing problem of KRD in Southwestern China.

Permaculture

A conjunction of the words "permanent" and "agriculture," the term "permaculture" first originated in a collaborative publication between David Holmgren and Bill Madison to describe an "integrated, evolving system of perennial or self-perpetuating plant and animal species useful to man" and as integrated design science (Mollison & Holmgren, 1978; Holmgren, 2002). In essence, permaculture is intentionally designed through species selection and overall outline to mimic natural environmental relationships in order to produce enough food and fiber to sustain a community. Holmgren, in his writings, outlined the 12 principles of permaculture that summarize the vision of producing sustainable systems:

> 1) Observe and interact 2) Catch and store energy 3) Obtain a yield 4) Apply self-regulation and accept feedback 5) Use and value renewable resources and services 6) Produce no waste 7) Design from patterns to details 8) Integrate rather than segregate 9) Use small and slow solutions 10) Use and value diversity 11) Use edges and value the marginal 12) Creatively use and respond to change.
> (Holmgren, 2002)

Overall, permaculture's distinguishing philosophy is to work with nature rather than against it, examining the unique needs and characteristics of an area's people, land and architecture, and indigenous wildlife (llamas). Permaculture design has also been defined by its two overarching principles: "Each element performs many functions" and "Each important function is supported by many elements (Rhodes, 2015)." It emphasizes regeneration, not just sustainability. A permaculture system is meant to improve the area it is built in by some aspect whether in soil health or water holding capacity (Rhodes, 2015)

For example, the founder of Permaculture Research Institute, Geoff Lawton, established a 10 acre garden in the arid Jordan desert to demonstrate the restorative possibilities of permaculture. Located near the Dead Sea, this area was plagued by high soil salinity, heavy wind erosion and overgrazing. Lawton began by building swales on the natural contour of the landscape and mulching on top of each swale with locally produced organic matter and waste. He then planted both hardy nitrogen fixing trees and fruit trees on top of the swales. Within two years, the soil salinity had decreased, and the trees were producing fruit. Lawton hypothesizes that the mushrooms grown beneath the mulch secreted a waxy substance that repelled the salt and helped improve the soil health. By working with the natural resources available in Jordan, Lawton used the demonstration site to show the mitigative and restorative potential of permaculture design (Lawton, 2013).

Permaculture designs also stress intercropping or polyculture systems. In theory, by diversifying the systems crops production, designers better tailor the system to the areas unique features as well as take advantage of alleochemical properties in each plants (Jackson, 2002). Plant diversity encourages diversity among the pollinators, soil microorganisms, and natural enemies attracted to the system. Distinctive alleochemicals—chemical substances released to the environment by an organism that acts as a germinator or growth inhibitor to another organism—and companion planting entice beneficial insect populations and promote plant health (Rayberg, 2007).

As a distinctive part of permaculture is its site-specific application, few systematic, quantitative studies have been conducted on the anecdotally purported benefits of many permaculture designs. Additionally, the social and spiritual aspects involved in the general permaculture concept distract from the fundamental scientific principles that are being applied in this type of agricultural practice. Exaggerated and unfounded claims about the benefits of permaculture cloud over legitimate advantages, thus discouraging scientific exploration and encouraging fanaticism (Holmgren, 2002; Ferguson & Lovell, 2014).

Hugelkultur

In this study, we examined one agricultural technique within the permaculture design called *hugelkultur*, an etymologically German word that can translate into "mound culture." Even less research has been done on hugelkultur; when searching "hugelkultur" in Google Scholar, only a total of 39 results appear, of which only 2 are peer-reviewed journals, and the majority emphasize the qualitative benefits of the design.

In his book, *Sepp Hotlzer's Permaculture,* Austrian agriculturalist Sepp Holtzer first described these raised beds. Hugelkultur beds are made to imitate natural nutrient cycling found in wood decomposition and the high water holding capacities of organic detritus, while also improving bed structure, drainage properties and spacial efficiency.

The hugelkultur beds have used in both small and large scale operations and have been constructed by hand and with machinery. The beds are, in essence, large, layered piles of woody debris or other detritus of various sizes under a layer of soil. Hugel construction begins with stacking logs of various sizes either directly onto the ground or within a dugout trench. Small sticks and mulch are subsequently added to the pile followed by a layer of soil. Finally, seeds are sown directly onto the freshly made hugel so that plant cover can be established as soon as possible, reducing soil erosion (Wheaton, 2016; Holtzer, 2011; Permaculture Magazine, 2015).

Hypothetically, the decaying wood at the center of the hugel bed will act as a water reservoir and a low maintenance composting system. By using bulky materials, as opposed to smaller wood chips, hugelkultur avoids rapid soil acidification and over fertilization due to the slower decay of the larger material (Holtzer, 2011). The no-tillage management system prevents the rapid depletion of soil organic matter, as well as stabilizing soil structure.

In December 2013, we did a preliminary study on two existing hugels on private property in Bowling Green, Kentucky (N36.990700, W86.438326) examining the difference in water storage between hugel and nonhugel plots. The hugels were constructed using wood, mulch and limited soil obtained on site. Samples taken from the hugels contained an average of 59% water by gram while the samples from the control, flat land plots, contained 33% water per gram. Unfortunately, these hugels were transferred to another owner and destroyed.

To further study the water storage properties of hugelkultur, we conducted the following study. We propose that hugelkultur beds will demonstrate an increased water holding capacity in comparison to nonhugeled land, as well as comparing the performance of hugels over time.

CHAPTER 2

Methodology

Sampling

In this temporal and spatial analysis, soil samples were taken at two different locations in Bowling Green, Kentucky over the course of 102 days from April 28th, 2015 to August 8th, 2015 and again September 22nd during a mild drought period. Sampling was done biweekly with a 1.5 cm/ diameter soil corer. Hugel cores, unless halted by wood, were taken to 30 cm. Control samples were extracted until the corer hit rock. Each individual site featured two hugels of differing ages and control site where 5 cores were taken at each plot: one on each end and three spanning across the middle.

Site 1 was located at the Unitarian Universalist Church (N 36.972450, W -86.462412). The site had two hugels varying in both length and age. Hugel 1, 2.57 x 4.13 x 0.81 m, was establish in May 2013 using wood and soil located on site. Hay, leaves, and other grasses were mixed into the soil. Hugel 2, 2.53 x 11.85 x 0.77 m, was built in May 2014, again with wood and soil from on site. More soil was added in March 2015. The control plot was a 5.00 x 2.50 m plowed strip located in line with the two hugeled plots. The plot was plowed once at the beginning of sampling and left unplowed for the remainder of the season. Sampling began April 10th, 2015.

Site 2 was located on private property in a suburban neighborhood (N 36.979561, W -86.416342). Hugel 1 was 1.94 x 8.19 x 0.40 m, and Hugel 2 was 2.04 x 6.21 x 0.44 m. Both hugels were built March 2014 using wood for neighboring trees and aged firewood. The soil, comprised primarily of red clay, originated for trenches dug to make room for the hugels combined with a mix of leaves, compost, and hay. The control plot was a 4.00 x 2.00 m unplowed grassway located perpendicular to the two hugel plots. Sampling began April 21st, 2015.

To serve as a KRD test plot, we found an area of exposure limestone bed rock, as per a typical KRD area, in Bowling Green, KY (N 36.979346, W 86.513627). Samples were collected within 30 minutes of a rain event to obtain water saturated soil to exemplify peak soil moisture.

<u>Soil Analysis</u>

Percent Soil Moisture: Upon collecting Whirl-Pak sampling bags to prevent moisture loss, the sampled soil cores were weighed on an electric balance to 0.01g, and then transferring into a brown paper bag. The samples were then prepared to be oven dried in an oven as follows: Air dried soil was ground, reweighed, transferred into clean, dry aluminum tins, and placed into the oven to dry overnight at 120^{o}C with the lid removed. After samples dried to a consistent weight, the samples were immediately weighed with the lid replaced to obtain percent soil moisture.

We used a modified formula for the volume of an elliptical cylinder

$$V = \frac{1}{2}(\frac{2\pi hwl}{4})) \qquad (1)$$

Location (Lat/Long)	Sample Name	Date Established	Volume (cm^3)	Area (cm^2)	Source Material
36.972450, -86.462412	Site 1 Hugel 1 (S1H1)	May 2013	6.75×10^6	106141	Onsite trees and soil, hay and leaves
	Site 1 Hugel 2 (S1H2)	May 2014	1.81×10^7	299805	
	Site 1 Control (S1C)	N/A	N/A	1.25×10^5	
36.979561, -86.416342	Site 2 Hugel 1 (S2H1)	March 2014	9.93×10^6	158886	Nearby trees, aged firewood, onsite soil
	Site 2 Hugel 1 (S2H2)		8.76×10^6	126684	
	Site 2 Control (S2C)	N/A	N/A	8.00×10^4	

Table 1 Location, working name, date established, volume in cm^3, area in cm^3, and source material for each of the sampled hugels

where V is the hugel volume in cm^2, *h* is the height in cm, *w* is the width in cm, and *l* is the length in cm to determine the volume of each hugel. Using the wet and dry weights to ascertain grams of water present per volume of sample core, we multiplied the volume of the hugel of origin by the amount of water per volume of soil core to estimate the amount of water present in each hugel.

The percentage water by gram of soil was calculated by dividing grams of water found in each sample by the total wet weight of the sample.

To project the amount of water that could be held in a 1-hectare field with hugels, if hugels were built to widths corresponding to each test hugel and a footpath of equivalent width was left in between each hugel, the water present per volume of soil core sample was multiplied by the volume of a hypothetical 100 meter long hugel and the number of such hugels that could be built in a hectare. A similar formula was applied to the desertified samples.

Because the data on the percent water by mass was expected to be a non-Gaussian distribution, we used a nonparametric Mann-Whitney test on IBM SPSS 23 on the independent samples to determine statistical significance. Using the decimal fraction of the water held within the hugel and control plots, we determined the driest and wettest sample days, June 19, 2015 and June 3rd, 2015, respectively. We combined the data from Site 1 and Site 2 to calculate the median, U value and significance for each of those days.

Precipitation data were obtained through the Kentucky Mesonet (University, 2016).

CHAPTER 3

Results

Over the course of three months, the water concentration levels in the hugels stayed consistently high; fluctuations in moisture reflected precipitation levels as well as the percent water per gram of soil (Figure 1; Figure 2).

In general, the hugel samples contained a higher percentage of water when compared to the control sample. At the Site 1, Hugel 1 had a 26.94 ± 2.0% *SE* (where *SE* is equal to standard error) average water per gram of soil, Hugel 2 had an average 21.97 ± 1.5%, and the control plot had 17.16 ± 1.2%. At Site 2, Hugel 1 had a 24.89% ± 1.4 average water per gram of soil, Hugel 2 had an average 31.86 ± 1.7%, and the control plot had 23.97 ± 3.0%. The average percentage of water in the saturated KRD soil was 27 ± 5.0%.

The saturated sample taken on KRD land, an area of bare karst rock, showed an average soil depth of *M* = 7.74 cm ± 2.5 *SD* (where *SD* is equal to the standard deviation) and was projected to hold 154,000 kg/Ha. When compared to the KRD site, the hugeled plot demonstrated a much higher water holding potential *M* = 955,084 ± 51,038 *SE* kg/Ha. Even through the dry weather periods, hugels contained more water than that held in a water saturated KRD plot.

Results from the Mann-Whitney U test showed that we could reject the null hypothesis; the difference between the control plots and the hugel plots are statically significant. For the driest day, the median decimal fraction of water in the hugels was 0.2011 and in the control, 0.1654; the distributions in the two groups differed significantly (Mann–Whitney U = 47.0000, n = 30, P = 0.019[1]). The median decimal fraction of water in the hugels on wettest day was 0.2496 and in the control, 0.2136; the distributions in the two groups differed significantly (Mann–Whitney U = 19.0000, n = 30, P = 1.265 E4[1]).

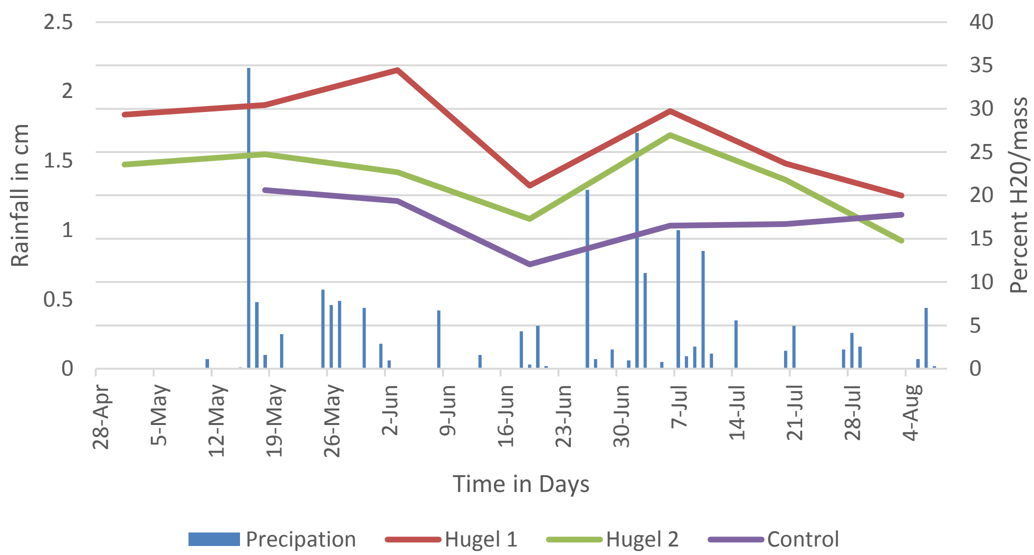

Figure 1 Measure of the percent of water by mass for each of the hugel located at Site 2, and the control plot. Precipitation data from April 28 – August 8, 2015.

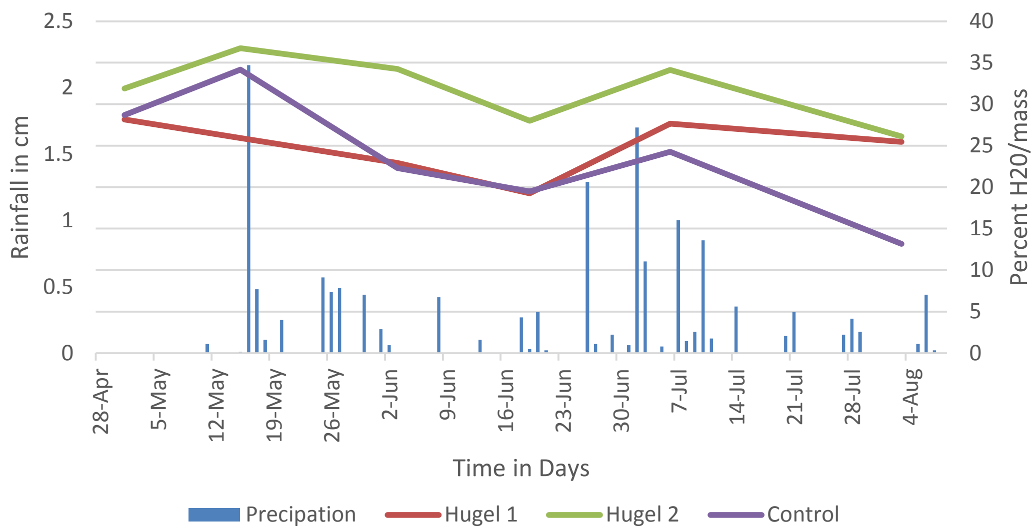

Figure 2 Measure of the percent of water by mass for each of the hugel located at Site 2, and the control plot. Precipitation data from April 28 – August 8, 2015.

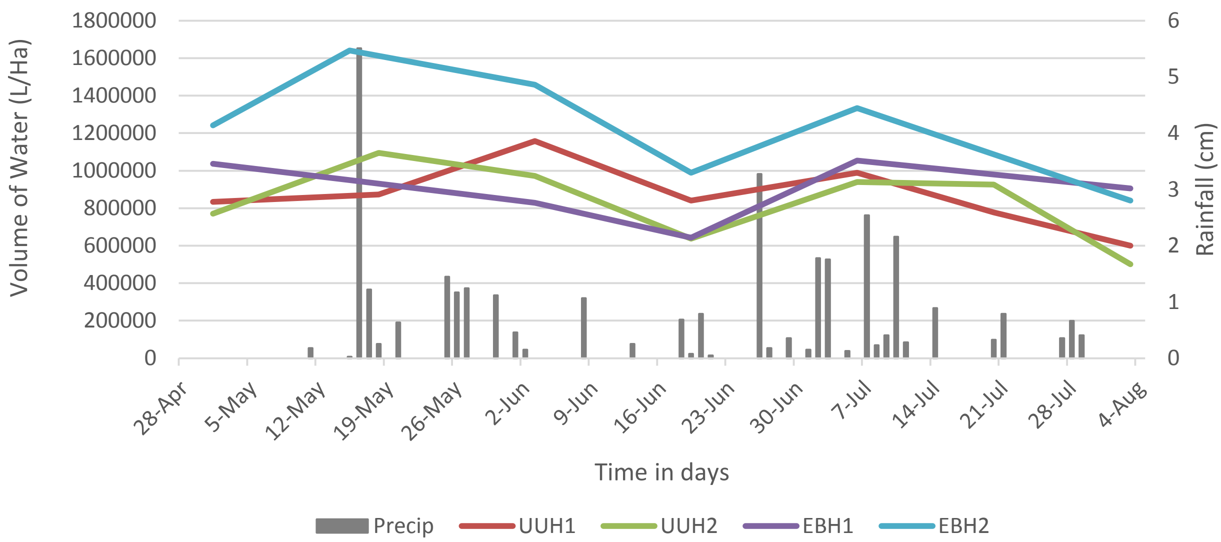

Figure 3 The hypothetical amount of water contained in a 1-hectacre field of hugel. Projections are based of the amount of water per gram in held soil samples for each of the hugels. Precipation data from April 28 – August 4, 2015.

CHAPTER 4

Discussion

Although hugels required a large amount of initial input of organic material (soil, compost, logs), they can be used for years afterward as a no-till agricultural system, one anecdotally shown to be a lower maintenance system. This study suggests that hugel construction could greatly increase water stored on KRD lands (Figure 1). One Ha of hugels contains 3 to 10 times more water than a flat plot of KRD land. In the same amount of land, farmers would be able to store and use more water, and use less irrigation, than if they depended on traditional row cropping. The results of this study support our hypothesis of an increased water holding potential in areas of hugelkultur. It has potential implications for future productivity of agricultural in areas affected by KRD.

The previous study, utilizing samples from December 2013, provides a better demonstration of the benefits of hugelkultur using building methods of the sampled hugels more closely mimic the conditions in China. Those hugels were constructed using wood, mulch and limited soil obtained on site. Even with minimal treatment, hugel samples contained almost twice as much water as the flat plots.

The hugels sampled in this study also demonstrated a similarly higher percentage of water by gram of soil when compared to the control plots. This consistency in the amount of water stored across time and at different locations indicates an even stronger potential for higher water capacity in hugelkultur systems.

According to the Mann-Whitney test, there was a significant difference in the driest and the wettest days, and we rejected the null hypothesis. At first glance, it seems counterintuitive that the wettest day are more statistically significant than the driest day. However, this could possibly be explained by the absorptive nature of the organic matter present in the hugels.

Among the most difficult challenges to be faced in implementing hugelkultur practices in China would be the availability of resources. Southwestern China, once famous for its old growth forests, now suffers from a shortage of trees. In fact, one of the leading factors suspected of causing KRD is large-scale deforestation. Originally triggered by national policy changes in the late 1950s, a growing dependence on the timber industry in both the agricultural and commercial sectors vastly contributed to the depletion of the forests (Xu & Wilkes, 2004).

Rural Chinese farmers would need to depend on an alternative source of organic material to base the hugel bed on. This could come in the form of compost generated throughout the daily lives of villagers: food wastes, animal manure, etc. Basing a hugel bed on smaller organic materials, without having the slow decay benefits of large, woody materials, would present difficulties in the longevity of the hugels. However, after the initial, organic waste-based hugels are established, a variety of tree species could be planted and grown to maturity on top of them, and in turn, used for establishing wood-based hugels.

In order to be applied in the KRD areas in southwestern China, hugelkultur needs to be effective in several arenas: practical building methods, agricultural yield, and water holding capacity. This study demonstrates its effectiveness in water holding capacity, and research on the yield qualities of hugels is currently being studied. As for construction practicality, flexibility in building materials and the possibility of self-propagation through on-hugel tree cultivation increase the accessibility of productive hugelkultur systems. These systems could be established on the outskirt of rural villages impacted by KRD using available soil in combination with assorted organic matter. Trees could be planted into these hugels along with other indigenous edible or economically valuable plants to create a sustainable, profitable system.

During March 2016, I, along with Dr. Chris Groves, traveled to Guangzhou to the International Symposium on Water Management and Ecological Development. There I presented these findings to several of the leading experts on Chinese karst landscapes and karst rocky desertification. When we discussed the problem of using a wood core for the hugels, they agreed that it would not be practical. One of the alternative materials mentioned was rice grass. After harvesting rice, farmers clear the field of the grass and traditionally burn it. Although the burning practices have now been outlawed, this mass of organic matter is still left unused, releasing carbon into the atmosphere. Apparently not suitable for mulch, the rice grass contains organic mass that is not currently being utilized. If this rice grass could be repurposed as a form of agricultural input instead of waste product, that method would have a great chance of becoming adopted on a more widespread basis because of its general abundance. The next step would be to experiment with rice grass as the basis of hugelkultur beds or adapt a different permaculture method better suited for the conditions in southwestern China.

While this study demonstrates the water holding qualities of hugelkultur, research on permaculture and specifically, hugelkultur remains sparse. There appears to be a large potential from permaculture, in its many forms, to be beneficial from both an agricultural and a land restoration perspective; however, without quantitative data to support anecdotal and qualitative demonstrates, permaculture will not be accepted on a large scale. In order to become a more widely recognized and accepted form of alternative and sustainable agriculture, more quantitative research on the water, nutrient, and restorative capacities of permaculture need to be conducted.

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