

Spring 2014

Alternative Irrigation Methods: Structured Water in the context of a Growing Global Food Crisis due to Water Shortages

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Alternative Irrigation Methods; Structured Water in the context of a Growing Global Food Crisis due to Water Shortages

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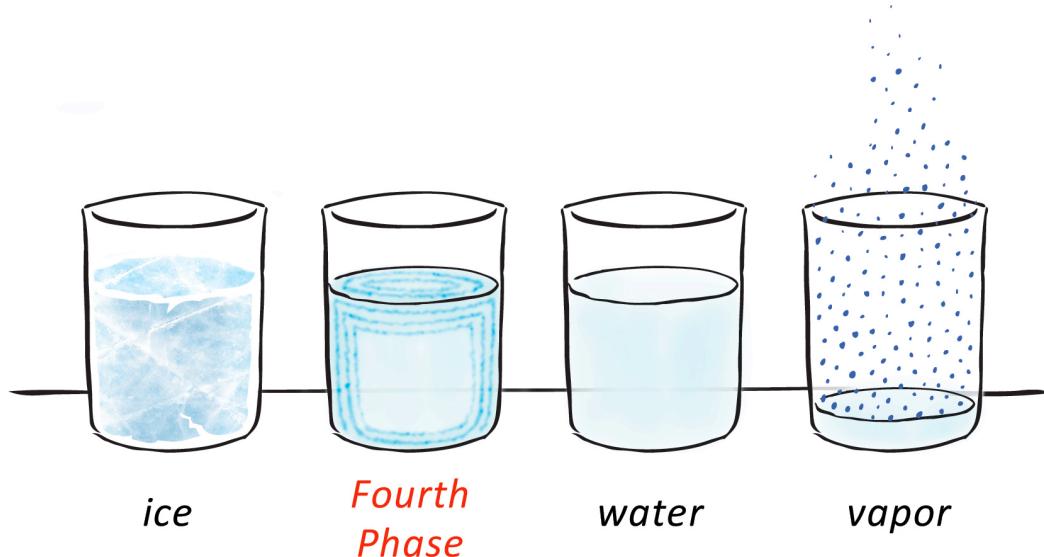


Figure 1. Fourth Phase of Water (Pollack 2013)

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April 2014

Introduction

Water scarcity presents this century's biggest challenge for humankind. Most fresh water in the world (roughly two-thirds) is used for growing crops. Agriculture thus is the largest sink for fresh water on this Planet. Lester Brown has alerted global political leaders and corporations by documenting evidence as given below that the collapse of our modern civilization is likely due to water shortages and food economy. Therefore, the conservation of water on farms is of vital importance for sustainability and dealing with the effects of climate change such as droughts. This most pressing issue of our times is addressed in this paper by researching alternative methods of irrigation. Our focus is on an exciting new field in water science; structured water. Also known as the fourth phase of water, structured water has a molecular structure that is arranged in a liquid crystal. In this paper, we experiment with this type of water to see its hydration and yield effects on sprouts. In addition, we put structured water into the larger context of alternative irrigation as a method to address a growing global food crisis due to water shortages.

Significance

'How to grow food with less water' is perhaps the most fundamental question in exploring sustainability from a scientific standpoint. Conventional methods to conserve water such as drip-irrigation have been researched and implemented over many years. However, the understanding of unconventional methods needs much greater and urgent attention than is being given at present. One such method is the structuring of water into crystalline patterns, also known as the fourth phase of water or structured water. In his excellent review of water structure,

Rustum Roy features various studies observing the structure of water with Raman spectroscopy and infrared spectroscopy (Roy 2004). In addition, there are a variety of methods to alter the structure of water without changing composition (Roy 2004). This paper uses vortexing, a technology further described in Appendix A and D.

In agriculture, the application of structured water to plants needs to be much better understood. After generations of people using this technology, preliminary research showing increased yield and peer-reviewed articles suggesting the existence of liquid crystals in structured water, the time is ripe to give it proper attention. While Roy offers a great review of the structure of water (Roy 2004), there is clear need of a comprehensive study that researches and analyzes the application of structured water. This paper is a step in this direction that serves to combine a scientific background to the topic of structured water with a real-time experiment of applying this water to testing its effect on the yield of sprouts. This research was done to further the investigation of alternative methods of irrigation management in a water-scarce world.

Literature Review

This section reviews the work and credentials of the main authors used for the information in this paper. Authors are organized and grouped in chronological order of when they appear in the paper. You may skip this section and use it as a reference while reading the paper.

The first and perhaps most important author in the section describing the current dire water situation is Lester Brown, founder of the Earth Policy Institute as well as the Worldwatch Institute. Brown is a long-time evaluator of global environmental health and helps us to understand the dire water situation (Brown, 2010; Brown 2014) while emphasizing the critical issues of food and farming (Brown, 2009; Brown 2012). Despite warning the population about the situation, Brown also brings positivity to the table, showing us how to change our situation with positive action centered around policy and economics (Brown, 2001; Brown 2003). J.S. Wallace adds a positive perspective on the potential of water efficiency. Wallace, former director of the Institute of Hydrology in the U.K. with various publications in the Journal of Hydrology, helps us to understand how to increase water use efficiency in agriculture in order to meet the needs of future populations (Wallace, 2000). Sandra Postel, founder of the Global Water Policy Project aiming to improve the water situation with policy, informs us what will happen when groundwater aquifers are depleted (Postel, 1999) and gives us a broad overview of the world's fresh water resources (Postel, 1993), a field where she is known as one of the main authorities. This paper also cites Postel's paper on drip irrigation, where she reviews the feasibility and challenges for small farmers who are or want to be using drip irrigation (Postel 2001). Peter Gleick, another respected authority in the freshwater world, informs us how we can rethink

policy and economics to shift the paradigm in the current water world and use water more efficiently (Gleick, 2000). In his paper, Gleick also terms the concept ‘peak water’, which is the essentially the over pumping of aquifers faster than they recharge (Gleick, 2000). This concept is used all over the world and appears in this paper.

The drip irrigation section begins with S. Sheng-Han, who wrote the *Agriculturalists Book of China*. This book has a great section on how drip irrigation was used in many forms in ancient China (Sheng-Han, 1974) and is important for this paper to understand the roots of drip irrigation more than 2000 years ago. Jeffrey Dahlberg also reminds of drip’s extensive history in his PhD thesis at the University of Arizona (Dahlberg 1987). Nakayama et al. have a great review of the precursor to drip irrigation, trickle irrigation, and make the interesting connection to Colorado being the first state to reject drip irrigation (Nakayama 1986). Alon Tal, a leading Israeli environmental activist and founder of the ‘Green Movement’ in Israel, adds a great overview of the history water management in Israel as well as a focus on the development and effectiveness of drip irrigation (Tal, 2006).

The first author in modern science progression section is Mario Beauregard. Dr. Beauregard is important in this paper, because he, although focusing on neuroscience, describes very well in his Spiritual Brain how modern science is often run by materialist ideologies and common ways of thinking that are denying the evidence of progressive research (Beauregard, 2007). Thomas Kuhn, former physicist at Harvard, M.I.T. and Princeton, adds a great deal this debate in his publication *The Structure of Scientific Revolutions*, where he helps us to understand the concept ‘paradigm shift’ by giving examples and trends showing that modern science takes time to shift established ways of thinking to accept new theories even if these new theories are

rooted in evidence (Kuhn, 2012). Edward Rosen gives us a great context of how technologies come to the mainstream. He describes Galileo's first struggles of rejection and denial before becoming accepted (Rosen, 1966).

The structured water section begins with J. Morgan, who did the very first testing of the structure of water via X-Ray (Morgan 1938). Morgan essentially was the first one to 'see' the molecular structure of water. We include Thomas Kuehne in this paper, because he has just recently confirmed the original tetrahedral bonding model made by Morgan (Kuehne 2013). Theodor Schwenk. Schwenk, founder of the Institute for Flow in Southern Germany, is known for promoting the concept of 'water consciousness' and, in his book *The Sensitive Chaos* urges people in Germany and the world to look at the earth as one organism (Schwenk, 1976). In addition, Schwenk introduces the vortex mechanism in his book (Schwenk, 1976). Recognizing the vortex as the underlying mechanism of water movement in nature has inspired the copying of this movement to create structured water for the experiment in this paper. Frederick Abernathy and R. Wille offer a basic review of vortex streets in modern journal (Wille 1960) which complement Schwenk's original models. Martin Chaplin, Emeritus Professor of Applied Science at the London South Bank University, adds a great deal of information about the structuring of water. In one of his papers in the *Biophysical Journal*, he informs us about water clusters, which are essentially large clusters of water molecules stuck together that hinder effective hydration of cells (Chaplin, 2000). Rustum Roy, former professor of geochemistry and materials science at Penn State, and one of the pioneers in looking at water as a crystal material, gained many insights and published in several journal articles about the crystalline nature of water. In the publication used for this paper, Roy reviews the structure of liquid water and makes the

connection to how structured water is created in homeopathy (Roy, 2004). Dr. Gerald Pollack, Professor of Bioengineering at the University of Washington in Seattle and chief editor of the Water Journal, has researched structured water from a different angle and termed structured water the ‘fourth phase of water’. In this book on this very topic, *The Fourth Phase of Water*, he combines published knowledge with his own experiments in an attempt to explain many of the anomalies of water (Pollack, 2011). Osvaldo Chara from the University of Buenos Aires is one of the researchers who has actually measured hexagonal structured in water and gives a basic review and evidence for this in *Physics Letters* (Chara, 2011). Enzo Tiezzi, Professor of Physical Chemistry and founder of the Sienese School of Chemistry, has performed Nuclear Magnetic Resonance (NMR) testing on water and published on the hexagonal structure of water (Tiezzi, 2003). This internationally renowned chemist is one of the first people to have seen the crystalline phase of water. Dr. Claude Swanson, physicist at M.I.T. and Princeton and one of the leading authorities in ‘unconventional physics’, offers a review of structured water in his book, as well as defining the basic scientific evidence underlining water charged with subtle energy (Swanson, 2010).

The conclusion first features freelance environmental writer Renee Cho. Cho, staff blogger for the Columbia University Earth Institute, makes a very distinct and straight-forward argument for food waste being one of the primary factors in water waste (Cho, 2014). David Pimentel, former chairman of the Gasohol Panel of the Department of Energy, shows us the importance of looking at the nature of human diet (plant-based or meat-based) as a major factor for modern water usage (Pimentel, 2003). C. Ford Runge, director of the Center for International Food and Agricultural Policy, makes a very compelling argument for the effect of biofuels on

human food needs and describes how potentially biofuels could factor into the starvation of people in poverty (Runge, 2014). Bekete Shiferaw, former scientist at the International Maize and Wheat Improvement Center, provides great information on the importance of shifting cropping patterns as a way to combat groundwater depletion in semi-arid villages in India (Shiferaw, 2008). In the same paper, Shiferaw makes a great case for the effectiveness of water pricing policies in shifting water use patterns (Shiferaw, 2008). Wes Jackson, founder and current president of the Land Institute and author of several books, informs us about the potential of working with nature as opposed to biotechnology in order to grow food with less water (Jackson, 1991). Jackson, one of the leaders in the sustainable agriculture movement, is working to bring back perennials and promote polycultures.

Background

Modern civilization is facing a severe crisis in food security. Today, we are at the end of an unprecedented period of stable grain prices, food surplus and widely available fertile farmland (Brown, 2012). For the past 50 years, the ups and downs on the world grain market have been tightly controlled despite a few short irregularities. The mechanisms of releasing carryover stocks of grain with proper timing and devoting more fertile land to agriculture have resulted in a very stable world grain price (Brown, 2012). This time is over; our carryover stocks are now depleted and the available land is limited by poor soil due to modern chemical agriculture, translating into consistently higher grain prices in the past few years (Brown, 2012; Wallace, 2000). In much of the world, we are now dependent on what we produce in a given season, with no safety net.

The biggest factor in the food equation is fresh water. Lester Brown makes it clear that the “spread of water shortages poses the most immediate threat [to world grain production]. The challenge here is irrigation, which consumes 70 percent of the world's freshwater” (Wallace, 2000). Water scarcity directly translates into food scarcity; no water means no food. In this we are presented today with a unique situation in the water crisis; the depletion of our major aquifers. For hundreds of years, we have been relying on drawing up groundwater to feed our crops. This goes well only until the day there is no more water. Then crisis hits quickly. We have seen this in small countries such as Yemen or Syria, where “peak grain has followed peak water” (Brown, 2014, p. 1). In this instance, this means that grain production peaked after water consumption from aquifers increased above recharge rates. In theory, the beginning of peak grain

means that grain harvests decline in the future. Seeing the effects of peak grain in these small countries is a precursor of what could potentially happen on a larger scale; “Aquifer depletion now also threatens harvests in the big three grain producers – China, India and the US – that together produce half of the world's grain” (Brown, 2014, p. 1). The North China Plain, the Indian Punjab and the Ogallala Aquifer in the U.S. are fossil aquifers, which means they are recharging at very slow rates or not at all (Brown, 2001). Below the North China Plain, “an area that produces more than half of the country's wheat and a third of its corn”, groundwater tables are falling fast and have led to significant decreases in wheat and rice production in the past 20 years (Brown, 2009, p. 54). In the U.S., the Ogallala aquifer is being depleted as shown in Figure 2. This has dramatically decreased the irrigated area is slowly shrinking (Brown 2001).

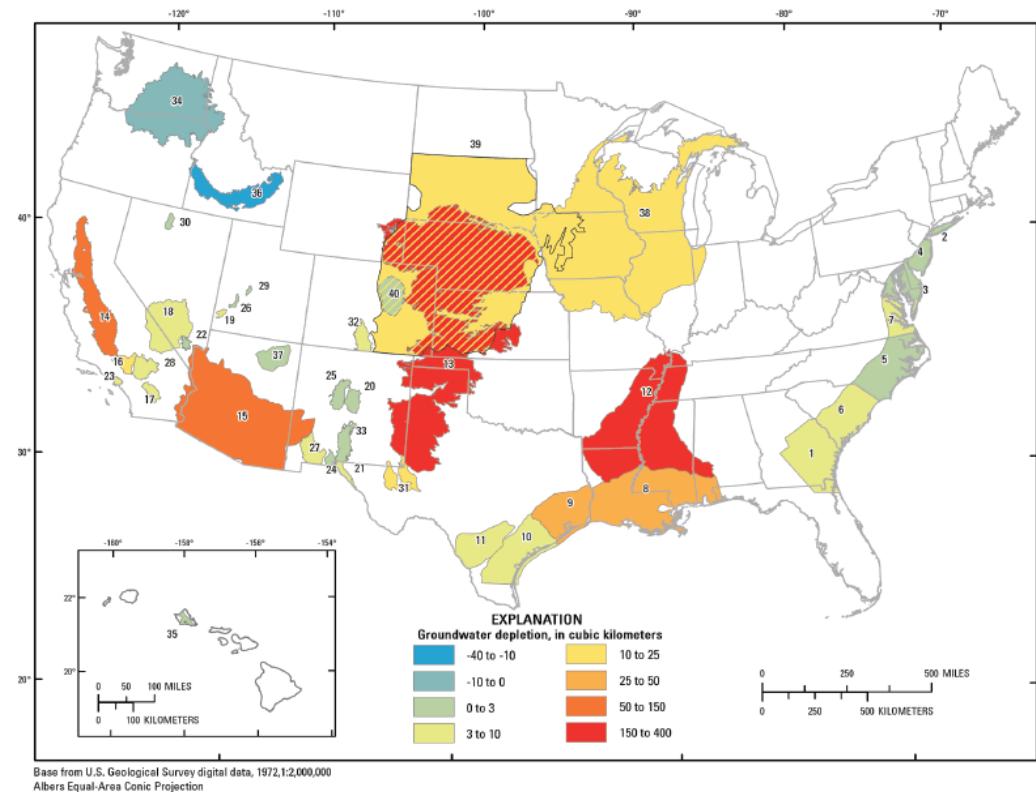
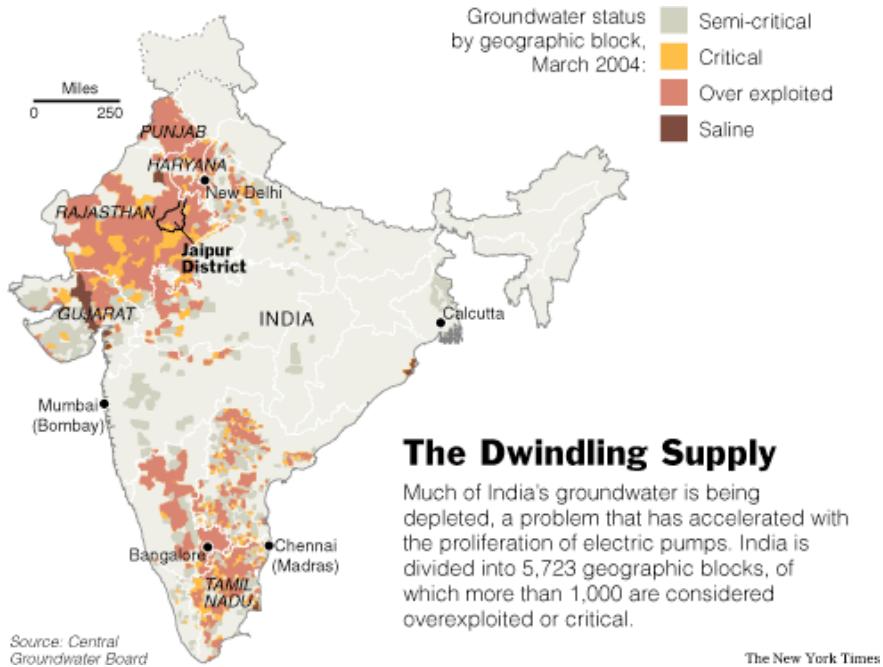


Figure 2. Map of the United States (excluding Alaska) showing cumulative groundwater depletion, 1900 through 2008, in 40 assessed aquifer systems or subareas. Index numbers are defined in table 1. Colors are hatched in the Dakota aquifer (area 39) where the aquifer overlaps with other aquifers having different values of depletion.

Figure 2. US Groundwater Depletion (Source: <https://water.usgs.gov/edu/gwdepletion.html>)



The Dwindling Supply

Much of India's groundwater is being depleted, a problem that has accelerated with the proliferation of electric pumps. India is divided into 5,723 geographic blocks, of which more than 1,000 are considered overexploited or critical.

The New York Times

The over pumping of the Indian Punjab also has had dire consequences; half of "traditional hand-dug wells [...] have already dried up" leading to mass suicides among farmers (Brown, 2009, p. 54). Groundwater

Depletion in India is

Figure 3. Groundwater Depletion in India (Source: <http://www.nytimes.com/2006/09/30/world/asia/30water2.html?pagewanted=a2>)

shown in Figure 3. At this point, "no country is immune to the effects of tightening food supplies, not even the U.S." (Brown, 2009, p. 56). Unless changes occur, it is only a matter of time that our world's breadbaskets will be very thirsty lacking the water necessary to produce all the food needed by a growing population.

We now need to make the best of what we have left. Postel points out that "as the Ogallala shrinks, water efficiency is increasingly the ticket to staying in business" (Postel 1999, n. pag.). Water efficiency is ultimately necessary. There is a huge potential in taking better care of water before it gets to our farms. Globally, about 30 % of water in irrigated agriculture is lost in transportation as water leaks or evaporates in ditches on the way to farms (Wallace, 2000). Another third is lost as evaporation on our farms (Postel, 1993). Improving transportation ditches and decreasing evaporation have a great potential to save water. Additionally, there is a huge

promise in technologies that reduce the amount of water needed to feed crops. Currently, drip irrigation is the global “gold standard for efficiency” (Brown 2003, n. pag.). Sandra Postel shows a massive reward in using drip technology, demonstrating “water savings of approximately 50 percent, crop yield increases of 30 percent to 70 percent, and shortened crop cycles” (Postel et al, 2001, p. 10). Drip irrigation is a key example of the type of technology that will play a vital role in conserving our remaining water.

In order to understand drip’s success, it is important to look into its history. Drip irrigation took a long route to get to the mainstream. With roots in ancient China more than 2000 years ago, drip irrigation was first put to the test of modern science in Germany in 1860 (Sheng-Han, 1974; Dahlberg, 1987). Fifty years later, the United States caught wind of the idea. Drip irrigation was rejected in Colorado in 1913, because it was “too expensive for practical use” (Nakayama, 1986, p.2). Another fifty years later, in the 1960s, Israeli engineers patented drip irrigation (Tal, 2006). This point in time is now recognized as the invention of drip irrigation, leading to a surge in usage “from 56,000 hectares worldwide in the mid-1970s [...] to 1.6 million hectares by 1991”, moving from vineyards and orchards to conventional crops (Postel, 1992, p. 104; Gleick, 2000). Since then, the technology has been thriving and now, in 2014, you can find the concept well described and documented in many modern textbooks for large universities.

In the introduction and acceptance of modern scientific theory and technologies, this progression is common. In a given paradigm, new ideas are often met with skepticism and doubt. This first inclination of scientists seems backwards, because “any doubt [...] can be labeled ‘unscientific’ in principle” (Beauregard, 2007, p. 24). In actuality, modern science is the practice of looking at new ideas with an open mind and doing research to evaluate their validity. Even

when evidence is collected, doubt often keeps progress from happening. Oftentimes, “materialist ideology trumps evidence” in modern science (Beauregard, 2007, p. xii). This is essentially the opposite of science. Even when research produces evidence, disbelief and doubt hinder the process of validation. Only when repeated research is shown, which can often take decades, anomalies lead to crisis and revolution eventually shifts the paradigm (Kuhn et al, 2012). Along that path, there is always rejection and disbelief. Take as an example the early Galileo Galilei, whose now well-accepted theories were initially “being received on all sides with skepticism and hostility” (Rosen, 1966, p. 263). Dismantling a worldview can take decades and centuries. Nevertheless, questioning of the current paradigm is fundamental for the progression of modern science. No idea that questions basic science should be discredited on the basis of doubt. In the case of structured water, Dr. Claude Swanson informs us that “many of the objections to the possibility of structured water are based on outdated concepts and lack of hard evidence” (Swanson, 2010). The lack of hard evidence should induce further research, not invalidity. The current water and food crises are compelling and the scientific community does not have decades to develop a consensus and make structured water technology widely applicable and affordable.

What is structured water and why do we care?

In the world of water, a lot of questioning is happening today. Structured water, the topic



of this paper, is highly controversial and at least partially contradicts some fundamental aspects of physics and biochemistry. Structured water is known by some as the fourth phase of water (next to solid, liquid and vapor) and simply means water that is arranged in a crystalline pattern at the molecular level. There are a variety of methods to structure water. Appendix B,C and D give a short review of the history of structured water, the effects of vortexing on water and structured water. Parts of the structured water topic have been researched for a decade and are now widely accepted. For example, a first look at the structure of water happened almost a century ago. The tetrahedral modeling of hydrogen bonds, initially suggested via X-Ray Analysis at M.I.T. in 1938 went through

Figure 4. Karman Vortex Street behind a stick (Schwenk 1976)

nearly eighty years of disbelief and further research before hitting the mainstream in 2013 (Morgan 1938, Kuehne 2013, Mainz Magazin 2013). Another important aspect of water, the basic spiraling mechanism of nature, was initially researched in the early 20th century as well, beginning with hydrologists Wolfram and Theodor

Schwenk in Germany. Schwenk has made us aware that, in nature, water always moves in vortices. This basic vortex mechanism of water movement has inspired the choice of vortexing as the method to structure water in this experiment. Initially introduced in the first half of the 20th century, Schwenk's ideas took decades to hit the mainstream. Now these ideas are included in the Karman Vortex Street as part of well-researched fluid dynamics (Schwenk 1976, Wille 1960, Abernathy 1962). Schwenk and Morgan's research has helped in understanding some of the elements of structured water, which are now accepted in mainstream science.

There are, however, parts of structured water properties that we are still unclear about. A lot of research today focuses on figuring out how tetrahedral structures connect to one another. Rustum Roy and Martin Chaplin have made some progress on figuring this out. Chaplin informs us that water which is sent through modern pipes with ninety degree angles often produce water clusters, water structures which are stuck together as opposed to organized into crystalline shapes (Chaplin 2000). Rustum Roy also describes water clusters as oligomers and show that water can "have its properties and hence its structure changed rather easily in non-linear ways without any change of composition" (Roy 2004). Possible structures for liquid water

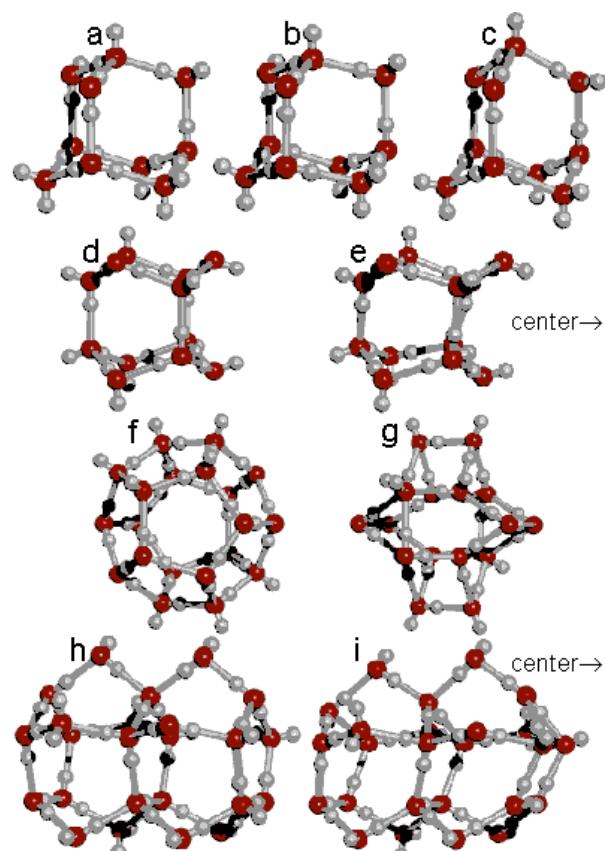


Figure 5. A variety of Oligomer Structures that are presumed to exist in liquid H₂O.

oligomers are shown above in Figure 5. Appendix H offers some more models of water structure including a potential bulk solution model. An absolute pioneer in the field of structured water is Prof. Gerald Pollack from the University of Washington, who termed the fourth phase of water. Pollack has found that water molecules tend to arrange in a specific way and become ordered at the surface of water, with a distinct hexagonal or crystal-like pattern (Pollack 2013). This is what he calls the fourth phase of water and is often referred to as structured water. Through Nuclear Magnetic Resonance (NMR) spectroscopy, we are now able to see this hexagonal structure and there are scientific publications in research journals on this topic (Chara et al. 2011, Tiezzi 2003). At the time of this writing, we know of a fourth phase of water and are able to see this

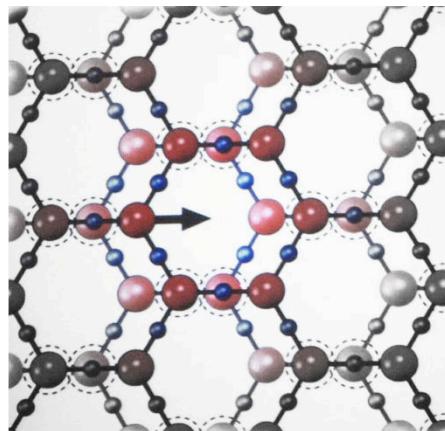
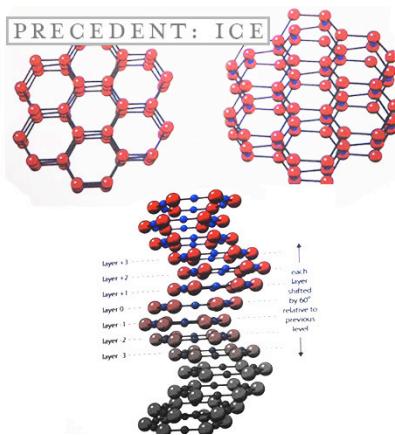


Figure 6. Hexagonal, or EZ structure of water (Pollack, 2013)

changes without any change in composition.

While the underlying science of structured water has a good foundation, the effectiveness of using structured water for agriculture needs more attention. Research about the application of structured water on farms is in its beginning stages. As of now, there is no research in scientific journals about how structured water affects plant growth. Structured water is mainly used in business, not academic research. There are several hundred companies all over the world already

through various spectroscopy techniques. We can measure that water can be either in clusters or hexagonal structures and that water structure constantly

selling structured water technology to farmers. Pursanova Technologies, the leading expert on structuring water through resonance technology, has been applied to growing corn in Iowa farms with positive results in the face of Midwestern drought where genetically modified (GM) corn plants have performed poorly (personal communication with the CEO of Pursanova 2013).

Business application of structured water only gives us limited results, because there is no control for comparison of yield. Business is mostly occupied with implementing and selling technology as opposed to doing academic research.

In order to evaluate the potential benefits of structured water technology in agriculture, a comprehensive scientific study is needed. As of now, academia has not spent much time in this field. There are no studies evaluating the yield of plants grown with structured water. Pursanova has done some very preliminary testing with sprouts grown with Pursanova Water shown in Appendix E. This work is very limited and needs to be expanded. In this study, we are essentially redoing this experiment with an increased sample size. The reason we are using sprouts is because they are a good indicator of what could happen on a large scale. Pursanova has expressed that they would like to see more studies done with structured water and sprouts (personal communication with the CEO of Pursanova). With a sample size ($n=30$), we extend Pursanova's work to evaluate the effectiveness of structured water in growing sprouts.

In this paper, it is proposed that structured water will likely increase sprout growth via the following mechanism; the movement of water through the vortex will alter the structure of water and create more 'structured water' in the bulk water solution. When looking at Figure 9 in Appendix H, more of the bulk water will be arranged in a hexagonal oligomer structure. This is a change that spectroscopy allows us to see. A different O-H stretch indicates that structured

water has decreased surface tension (Swanson, 2010). Due to its decreased surface tension and altered hydrogen bond angles, structured water is able to “better penetrate cell walls, allowing improved hydration and bioavailability” (Swanson, 2010, p. 229). Ultimately, this greater hydration of cells walls may lead to greater yield in plants.

In this paper, we will use our experiment with structured water to evaluate whether or not structured water shows a promise for agriculture and needs research on a larger scale. The aim of this study is to show that structured water research reaffirms the scientific tradition of investigation of new theories and technologies. From this perspective, we evaluate the importance of structured water technology for the future of agriculture.

Hypothesis

In this experimental study, we are interested in answering the question of: if and how much structured water can increase the growth of sprouts. Specifically, we raise the following hypothesis:

H0: There is no difference in growth between sprouts watered with structured water compared to tap water.

H1: Sprouts watered with structured water grow more than sprouts watered with tap water.

Methods

Study Design

Our study design is prospective, randomized and single-centered.

All experimentation was done at the Cooperative Institute for Research in Environmental

Sciences (CIRES), University of Colorado Campus, Boulder, CO.

We grouped our sprouts in two categories, (X) and (B):

(X) sprouts watered with structured water.

(B) sprouts watered with tap water.

Both the structured water and the tap water samples are originally taken from the City of Boulder tap water.

Procedures

30 Jars were filled with 24 grams of mung beans each, resulting in 15 Jars of 360 grams for each type of water. The Jars were randomly picked with an Excel sheet. The structured water was prepared via vortexing through an upside down glass bottle. Then, the jars were filled with structured water and tap water respectively & arranged on a table. 12 hours later, the water in the Jars was removed and the Jars placed back in the sprouting box.

For 5 days, the sprouts were watered with the assigned water, tap or structured, respectively, for 5 minutes each two times a day, roughly 12 hours apart. The water was vortexed before each new watering to create structured water. On the sixth day, the sprouts were watered once and left to dry for 24 hours. The same experiment was run one month later with alfalfa seeds. We started with 15 grams in each Jar.

Evaluation Tools

After the sixth day, the sprouts were weighed on a scale.

Documentation

All data was recorded by hand in a Log Book.

For further statistical processing, handwritten data was transferred to an Excel Document on a Computer.

Statistics

We performed an independent t-test to calculate the level of significance. The program R Commander was used for this purpose.

Results

Both experiments with mung beans and alfalfa seeds showed a significant increase in growth, 6.25% and 15.1% respectively, when feeding sprouts structured water compared to tap water.

Table 1. Mung bean sprouts fed with structured water (n=15) showed an increase of 6.25% in average growth compared to mung bean sprouts fed with tap water (n=15). Our results were statistically significant (p=0.0014).

Water Used	Average Growth (g) +/- Standard Deviation
Tap Water	51.2 +/- 1.15
Structured Water	54.4 +/- 3.07

Table 2. Alfalfa sprouts fed with structured water (n=15) showed an increase of 15.1% in average growth compared to alfalfa sprouts fed with tap water (n=15). Our results were

statistically significant ($p=3.52e-09$).

Water Used	Average Growth (g) +/- Standard Deviation
Tap Water	59.8 +/- 4.40
Structured Water	68.8 +/- 6.38

Our data suggests that structured water increases the growth of sprouts. The effect was more drastic when applying structured water to alfalfa sprouts (15.1% more growth than with tap water) compared to mung bean sprouts (6.25% more growth than with tap water).

Complications

The major complication of this study is that we were working with a small data set. Further studies need to create more data to research the clues and insights we have gained through this study. A future study could also benefit from taking a few basic measurements after spiraling the water. Information on temperature, pH, density, dissolved oxygen content change and more needs to be gained to include more controlled variables. We have already taken some basic preliminary pH measurements indicating drastic increases (up to .5 points on the pH scale). More testing needs to be done here to effectively account for this variable. Finally, this study was not blinded.

Discussion

While limited in scope, our study points to a promising future for structured water in agriculture. The proposed mechanism that hydration leads to better sprout growth has shown to be effective in the experiment on this scale. Compared to tap water which contains water clusters (Chaplin 2000), structured water is able to better hydrate sprouts because of its crystalline structure (Swanson 2010). This increased hydration leads to better growth and thus yield. The data we collected for both mung beans and alfalfa seeds confirm this proposed mechanism on a small scale with statistical significance.

There are some important points to take away from this study to plan further studies. For example, we found that different plants show varied reactions to structured water. Alfalfa sprouts had a higher growth difference than mung beans. More research with different plants may lead to different results. It would be very beneficial to find the plants that are most responsive to structured water technology and it is likely that many sprouts experience higher or lower growth differences than shown in our experiment. In addition, it is important to notice that our growth difference numbers may become a lot more drastic when applied to the full growth cycle of a plant. Potentially, the main effect of structured water happens after the sprouting stage. We are unsure about how a plant is affected during its different stages until maturity. A relatively small growth difference in sprout growth could easily translate into a large (or small) yield increase in a full grown plant. These are some of the uncertainties we are not able to cover in this paper. We suggest that repeated experimentation and further studies on this topic are done. This small-scale study is only a precursor to studying the effects of structured water on large-scale farms. Nevertheless, our positive results of using structured water along with the preliminary research

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done by Pursanova Technologies suggest real promise.

Our results of increased sprout growth on a small scale do not yet translate into large-scale agriculture. The technique used in this research, vortexing water by hand, was effective to show growth differences but it cannot be transferred as easily to a larger scale such as a 100 acre monoculture farm. In addition, testing needs to be done to see how much vortexing increases the part of the bulk solution that is structured water. This paper assumes that vortexing creates structured water, but in actuality, this is an uncertainty that needs further research. That said, our results hold promise that large-scale experiments with structured water may show increased yield. We therefore strongly recommend a more comprehensive study on this topic. In order to evaluate effects in large-scale agriculture, we need experimentation with existing structured water technologies designed for large farms. The Martinsverwirbler, a technology that vortexes water through oppositely charged metals (silver and gold) is being used in Germany and we recommend testing with it. Pursanova also represents real promise and needs to be tested next to a control on a large scale. As mentioned above, Pursanova has only done preliminary tests comparing sprouts watered with Pursanova water to a control (Appendix E) and has expressed interest in larger scale studies using Pursanova water and other structured water growing sprouts and full plants (personal communication with the CEO of Pursanova). Companies like Pursanova actually welcome research in the field, because they may not afford the time or money to do research themselves. In general, we need more research and more rigor in the structured water field.

Conclusion

The future of fresh water and abundant food is uncertain in many parts of the world. We have been warned about the potentially dire consequences of continued aquifer depletion (Postel, 1999; Gleick, 2000). If we run out of water in our main aquifers, we are faced with a growing global food crisis that could take down civilization (Brown, 2009). To avoid this scenario, we must employ a variety of actions to use less water. Current water use is not sustainable and many actions can be taken to conserve water. Limiting food waste, shifting from an animal-centric diet to a plant-based diet and using biofuel grains for food are options to feed the growing population with less water. These three opportunities are outlined in Appendix F. Water shortage also will lead farmers all over the world choose crops that need less water. Shifting from water-intensive crops to more water-efficient crops is an effective way to save fresh water. Wes Jackson, one of the pioneers of re-introducing perennial crops into modern agriculture in the U.S., is leading the way in keeping the water in our plants and soils instead of getting lost through evaporation (Jackson 1991). Water markets also show a great promise in limiting groundwater depletion. Efficiency and water markets are reviewed in Appendix G.

The focus of this paper, water efficiency technologies, suggest real promise in conserving water in agriculture. Drip irrigation is very successful in irrigated agriculture especially with dry soils and should be implemented wherever possible. Drip shows us that developing and bringing technologies to the mainstream takes time and caution. The paradigm shifted for drip irrigation with repeated experimentation and now it is a well-accepted technique to use water more efficiently in agriculture. Structured water is still in this progression and needs more scientific inquiry. While still moving slowly in academic research, structured water is already breaking

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through on the commercial level. Hundreds of water companies are selling structured water. For now, this business application is the main promise of structured water in large-scale agriculture is it. Pursanova Technologies are implementing structured water technology in large-scale agriculture fields in Iowa. The farms in Iowa have all reported great results with yield increases compared to previous seasons (personal communication with CEO of Pursanova 2013), but they switched their entire plots so there are no control yield values to compare for scientific research. Though effective from the commercial perspective, this does not effectively show evidence that structured water improves yield in agriculture.

This appearance of a technology in the commercial sector before academia is common in the scientific tradition of investigation of new theories and technologies. The history of drip irrigation shows us that a valuable technology may appear commercially and be used for decades before being researched and accepted in academia. Drip irrigation was long used in Israel commercially with official patents in 1960 (Tal, 2006). From the perspective of the scientific tradition of investigation of new theories and technologies, structured water research in agriculture may be at a similar point as drip irrigation was in 1960. With the right amount of research and data collection, structured water technology could potentially prove to be as important as drip irrigation to conserving water in agriculture. Scientific experimentation on a large-scale is needed to confirm these trends and get the attention of the mainstream. We need repeated experimentation at large universities. On a scientific level, there are still concerns with the technology and we are not clear about its effects yet. Further research at CIRES and the University of Colorado is recommended as well as in other universities in the U.S. and around the world.

The time is now is to gain further understanding about structured water, especially in the realm of large-scale agriculture. This paper suggests that structured water is a promising field in water conservation with a good foundation. We have no time to waste given the threat of food shortage due to lack of fresh water.

Summary

Water scarcity is the big topic of the 21st century. Farmers all over the world are struggling and food security is directly linked to using water wisely. Water conservation thus is among the most important factors for sustainability. Proper technology for this is crucial. The results of this study suggest a promising future for structured water in agriculture. We strongly recommend further research. In order to shift the paradigm, we need repeated experimentation and more data. That said, existing technologies such as drip irrigation are out there and we must use them today. In addition, reform needs to happen in various other areas; we need to shift agriculture from water-intensive crops to efficient ones, reform our water markets, limit water waste and reconsider the use of cereal grains for biofuel and livestock.

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Appendix A - The vortex

In nature, water moves in vortex patterns. This phenomenon has been studied by many early 20th century hydrologists such as Wolfram and Theodor Schwenk. In his “Sensitive Chaos”, Theodor Schwenk explains that water always wants to be in a cycle, a phenomenon that can be studied in Rivers, oceanic patterns & the growth of plants, which are - just like most other things on this planet - mostly water. Across different scales, the vortex exists in the most basic patterns of nature. Consider, for example, that all human skin pores employ a basic spiral shape, similar to our ears (Harman). In flowing water, one or several vortices are formed whenever waters of two different characteristics (such as warm & cold, slow & fast) connect (Schwenk). In rivers and small scale water flow, this phenomenon has been known as the Karman Vortex Street for about a century and is basic scientific knowledge in fluid dynamics research (Wille, 1960, Abernathy, 1962). The vortex can be seen in essentially all patterns of nature. Researchers and artists all over the world have been fascinated with these patterns. Leonardo daVinci, for example, used the Fibonacci sequence to describe the growth of plants, which are mostly water (Pangman). This sequence is a mathematical equation for a perfect spiral pattern. Nature behaves according to this vortex pattern and therefore nature’s primary medium, water, moves in vortices.

Appendix B - The structure of water

The molecular structure of water has been researched by modern scientists for at least 100 years. In this time, many scientists in the fields of conventional chemistry and biochemistry have focused and dedicated their time towards learning about the composition of water. Science has seen advances in understanding what water is composed of, what is in it, and how each water molecule acts by itself, while assuming a relatively uniform mixing and behavior of the water molecules. One of the leading water researchers of his time, Henry Frank, recognized in 1970 that “the individual water molecule is now well recognized” (Frank). On another part of the spectrum, far fewer researchers and people have dedicated their lives to learning about the structure rather than the composition of water. This focus of the molecular structure of water has brought forth some remarkable insights. A good majority of these have received a measurable amount of criticism, disbelief and confusion. In order to see the full picture, we must go back in time and evaluate the various attempts to measure and determine the structure of water. One of the first attempts was an X-ray analysis of water at M.I.T. in 1938. The basic idea of this study was to evaluate the molecular structure and basic nature of hydrogen bonds, the bonding of one hydrogen atom of one water molecule to an oxygen atom of another. It was found that water molecules tend to bond to 4 neighbor molecules tetrahedrally (Morgan). So in 1938, American scientists were able to physically see a basic structure of water. Since then, various methods, primarily different types of resonance spectroscopy, have been successfully applied to measure, see and analyze the structure of water (Dyke et al, Matubayasi et al). Despite receiving a considerable amount of critique, the original model of tetrahedral bonding of water molecules in 1938 has recently been confirmed by some researchers in Mainz, Germany in February 2013

(Kuehne 2013, Mainz Magazin). Another study in 2013 by a researcher at the Swiss Federal Laboratories for Materials Science and Technology adds that “it is well accepted that water is not a continuum fluid without structure: water molecules form a well-defined hydrogen (H)-bonding network, and water properties in the proximity of a surface differ substantially from those in bulk solution (Espinosa-Marzal, 2013). It took almost 80 years to get the main stream science to understand this phenomenon. The next step after this is to measure and understand how these tetrahedral structures are connected to one another. The later part of the 20th century has been filled with researchers trying to understand this part of the structure of water. Martin Chaplin, for example, has found that hydrogen bonds can form a network of water clusters containing up to 280 hydrogen bonded molecules (Chaplin, 2000). Rustum Roy has done a set of experiments to show that the structure of water can be changed by microwaves and radio waves (Roy, 2004). In addition, there are a variety of theories about the structural changes of water at different temperatures, densities, and more (Dyke et al, Matubayasi et al). The understanding of the structure of water is growing rapidly. In the past century, water science has made some leaps to get beyond the assumption of uniform mixing and started to understand how water behaves to form certain structures.

Appendix C - The Fourth Phase of Water

The most remarkable of water structures is the liquid crystalline phase. Conventional science knows three phases: liquid, solid and vapor. We now know of a fourth phase of water. Gerald Pollack, professor of biochemistry at the University of Washington, can be considered the leading expert in this field. Prof. Pollack has found that water molecules tend to arrange in a specific way and become ordered at the surface of water. This surface behavior has a distinct hexagonal pattern, much like a honey comb, which he calls a crystalline structure. Pollack says that the “crystalline structure grows at the interface between air and water. It is a stable zone [which] has a negative charge” (Pollack). Pollack calls this the fourth phase of water, or liquid crystalline water. This is what is otherwise known and often referred to as “ordered water” or “structured water”. This ordering of water has been confirmed in other studies. The 21st century has served as a breakthrough time for this; Chara et. al published an article in 2011 on the hexagonal structure of water and have done a great deal in physically measuring this quality (Chara). In addition, Enzo Tiezzi has contributed some insights in this field. He has used NMR spectroscopy to look at the nature of the hydrogen bonding and found similar results to Pollack: Water “by virtue of hydrogen bonds [is] structurally similar to a liquid crystal” (Tiezzi). This fourth phase of water is now becoming accepted research in the scientific community. Researchers all over the world are now starting to understand this liquid crystalline structure or fourth phase of water, measure it and learn about its benefits in various applications.

Appendix D - The effect of Vortexing on Water

Now that we have been introduced to the basics of the structure of water, the fourth phase of water and the vortex, it is time to look at the effect of vortex movement on water. When water is vortexed through a glass bottle, it comes out in an onion shape with a very large surface-air interface. This has five measurable effects on the quality of water. We will start with the most simple and work our way to the more complex phenomena:

1. Oxygenation

Oxygen from the air is nearly always present in water, either dissolved or in bubbles. Flowing out of a vortex, the large air-water interface increases and the water literally dissolves bubbles or oxygen from the air into the water at the molecular scale. The dissolved oxygen content is therefore slightly increased in vortexed water. Intuitively this makes sense; because the vortex increases the surface area of the water that is exposed to the air, the water is allowed intake oxygen. The amount depends on the type of vortex, the pressure of the water, and various other factors.

2. Viscosity and Surface Tension

Dr. Claude Swanson, PhD in Physics, has a great review of structured water in his book. He says that we have known for many years that centripetal vortexing of water “is consistent with a decrease in viscosity and surface tension of the water” (Swanson). This change allows the water to “better penetrate cell walls, allowing improved hydration and bioavailability” (Swanson).

3. Molecular rearrangement

Tap water often is delivered in the form of water clusters (Chaplin). Vortexing water likely rearranges some molecules into liquid crystalline water and therefore creates a larger portion of

the fourth phase of water. As of now, it is unclear how long this structure lasts. We know that hydrogen bonds often change as fast as hundreds of femtoseconds in bulk water (Wen). The nature of hydrogen bonds in water is inherently dynamic. However, we are not aware how fast the water changes back from the fourth phase to the third phase. Pangman et. al argue that structured water increases the strength of hydrogen bonds 20 to 250 times compared to bulk water (Pangman). We also are learning that organization provides a degree of stability so that hydrogen bonds are not as easily broken (Kuehne, 2013, Luck). The vortex does exactly that; it organizes the water into liquid crystals.

4. Change in pH

The layers of water flowing out of a vortex are temporarily in the fourth phase of water and have a net negative charge. This means the water is slightly more ionized. Therefore, the more of the fourth phase is present in water, the higher the alkalinity of the water. In theory, vortexing water thus increases the pH.

5. Temperature

While conventional science would assume that vortexing increases the water temperature due to the creation of friction, the opposite actually happens. Pollack describes this phenomenon as follows: because vortexed water likely transforms some bulk water into liquid crystalline water, it “feels cooler” meaning that vortexed water emits less radiant energy than normal water (Pollack). Vortexing has a cooling effect on water.

Application of the vortex

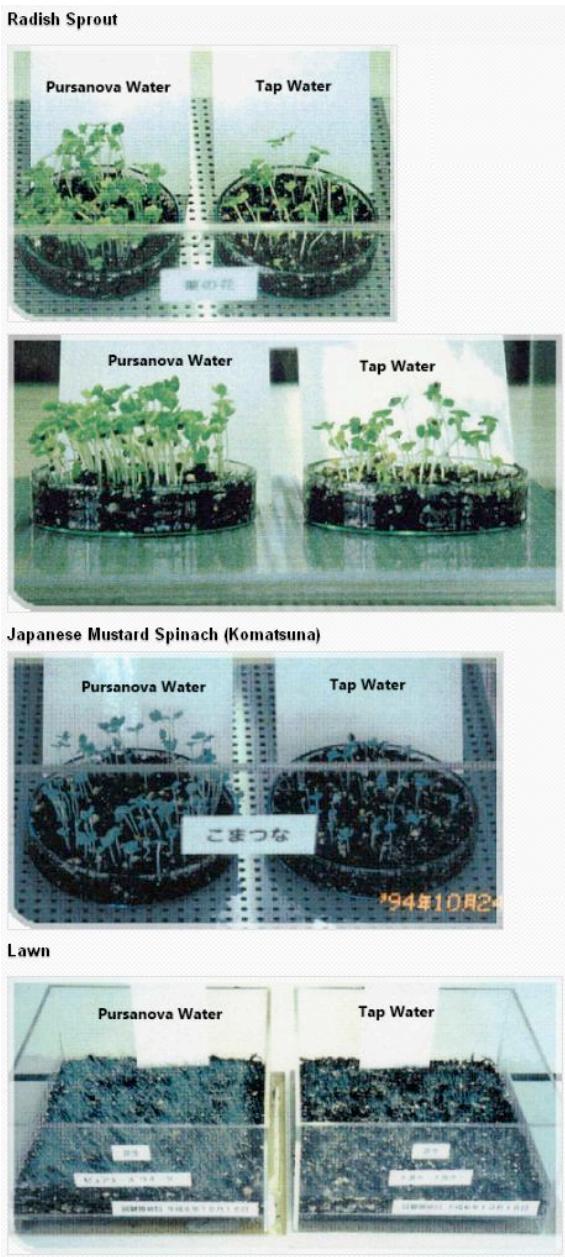
While science has tried to understand vortex movement and point to answers, a variety of people have already used this phenomenon based on their intuition. It may be assumed that ancient Egyptians, Mayans and so forth have used this most basic shape of nature. In this review, however, we focus on the past 100 years. In this time frame, a variety of people have used vortex flow to treat water. Primarily the concept been used for hydro mimicry, mimicking the way water moves in nature for water treatment devices that are essentially filterless filters. There is an abundance of companies & farmers who use different types of mechanisms to create ordered water, many claiming to produce better results for agriculture, food preservation, health and more (Wilkes). Viktor Schauberger, a legendary Austrian naturalist, is known for using the vortex for various purposes. Based on his knowledge, Wilhelm Martin created the “Martin Wasserwirbler”, which is a treatment based on water flowing through a water vortex (Fischer). This device is used today in a variety of German Bakeries who use this water to make a better tasting dough that uses less flour (Interview). A variety of informal experiments have been done in these bakeries with the Martinsverwirbler. In addition, most biodynamic farmers in Germany use a Martinsverwibler to water their crops (Fischer). In fact, vortexing water is the basis of biodynamic agriculture (Pollack). The understanding of farmers and bakers alike is that the vortex eliminates large water clusters and therefore the water is more able to penetrate cell walls. As mentioned earlier, Claude Swanson added that the decreases viscosity and surface tension of vortexed water allow “improved hydration and bioavailability” (Swanson). Another very popular device using vortices to enhance the quality of water is the so-called Flowform. John Wilkes describes various measured benefits such as increased plant growth, stronger resistance to pests,

decreases need of fertilizers and increased nutrient density from using Flowforms (Wilkes). Flowforms are used all over the world. However, just like the Martinsverwirbler, they lack scientific studies of their benefits, because they have mainly been used for business enterprises without a control group of detailed measurements. A comprehensive study analyzing the effects of vortexed water on plants does not exist as of the time of this writing.

A lack of scientific data also exists for numerous other water treatments based on water movement such as Pusanova Water Technology (PWT). Despite the abundance of application on farms, businesses, households and more, a comprehensive review is missing. Most water movement based treatments are used on a small scale, whether in small organic/ biodynamic farms, households, high-quality restaurants, resorts and more. Part of the dilemma here is that people using the technology are not interested in or lack time to create reproducible studies, because their main focus is business. On top of that, all treatments including the Martinsverwirbler and PWT have additional elements built into their treatment (Pusanova).

These additional elements have effects on the water.—

Appendix E - Preliminary Radish Sprout Experiments with Pursanova Water



To the left are pictures of very basic experiments with Pursanova Water in growing sprouts. While the sprouts show a difference, the sample size here is very small. This preliminary research has partly inspired us to do a sprouting experiment with structured water with a larger sample size ($n=30$).

Figure 7. Radish Sprout experiment done with Pursanova Technology (Pursanova)

Appendix F - Water Conservation

Next to water efficiency technologies, it is crucial to put into practice other ways to save fresh water. Many actions can be taken to conserve water on this planet. Perhaps the simplest and most effective way is to stop wasting food. “As much as half of the water used to grow food globally may be lost or wasted” (Cho 2014, n. pag.). Limiting food waste means limiting water waste. In addition, we need to reconsider the use for our grains on this Planet. A large portion of our grains (and therefore our water) goes directly to feed livestock. Currently “the US livestock population consumes more than 7 times as much grain as is consumed directly by the entire American population” (Pimentel, 2003, p. 661). This unnecessary stress on water is a direct result of animal-centric diet that is much more prevalent in the West than in the East. As a result, the Western world needs to seriously think about making changes to move towards a plant-based diet. An increasing amount of grains now also goes to biofuel. Some estimates predict that “ethanol plants will burn up to half of U.S. domestic corn supplies within a few years” (Runge 2007, n. pag.). These practices will need to shift now if we want to conserve water on this Planet while keeping our growing population with sufficient food.

Appendix G - Efficient Agriculture and Water Markets

Shifting from water-intensive crops to more water-efficient crops is an effective way to save fresh water. Wes Jackson, founder of the Land Institute, is one of the pioneers of re-introducing perennial crops into modern agriculture in the U.S. Perennial Crops, along with polycultures and intercropping are designed by nature to keep the water in our plants and soils (Jackson, 1991). This natural mechanism, however, is not necessary where there is temporarily enough groundwater. The need to save water in many places in the world is suppressed due to a virtually non-existent cost for pumping groundwater. In India, for instance, “the availability of free water for irrigation [coupled with indirect subsidies that lower the relative profitability of water-efficient dryland crops] is shifting cropping patterns in favor of water-intensive crops that should not be encouraged in water-deficit areas” (Shiferaw, 2008). Under these circumstances, sustainable groundwater pumping is not possible. It is noteworthy that rain-fed crops were widely used in the ancient Indian agriculture but it was changed to modern agriculture under British colonial rule. Water use today must to be regulated by a market or alternative mechanism. Clearly this is a not a perfect system, but it has shown promise in some areas of the world. A functioning example is Chile where the introduction of an innovative water market “fostered efficient use of water [and] facilitated a shift to high-value crops which use less water per unit value of output” (Schleyer, 1996). Water markets have the potential to reduce water usage. Ultimately, political & economic reforms are vital for water-efficiency next to innovative technology and shifting practices.

Appendix H – Water Oligomers and other Structures

Water is presumed to exist in a variety of structures that all have the same composition.

Below are some more complex water structures, also known as clusters. See Chaplin (2000) for more detailed pictures and reference.

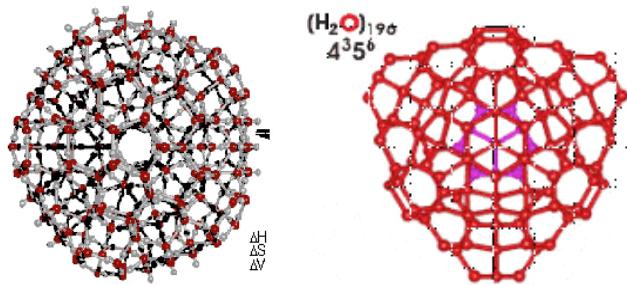


Figure 8. Complex Water Oligomers (Roy, 2004)

Rustum Roy has spent a considerable amount of his career studying the nano-heterogeneity of glasses. In his later research, he also found evidence for nano-heterogeneity in liquid water. He reports “liquid water (OH₂) like its remarkably similar analogue SiO₂, is not a homogeneous structure at the molecular level. It is a dynamic equilibrium among changing percentages of assemblages of different oligomers and polymer species” (Roy, 2004, p. 604). While we have gained lots of insights about the composition of water, research of the structure of water needs to be explored in more depth.

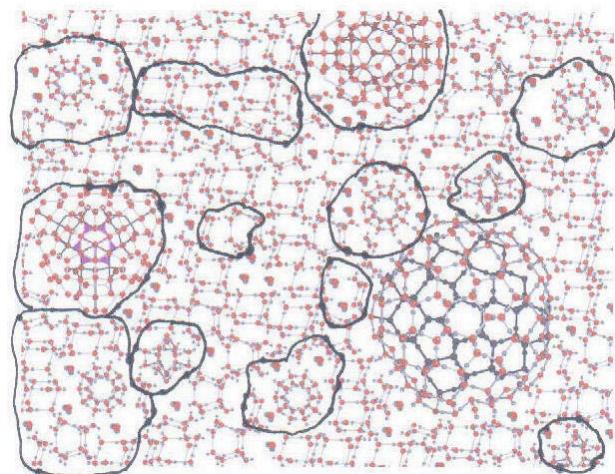


Figure 9. Potential heterogeneity of a bulk water solution (Roy, 2004)