Zizania aquatica L., Wild Rice;

An Evaluation of Cultivation, Domestication, and Production For Use in The United States

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EXECUTIVE SUMMARY

Native American tribes began the domestication of *Zizania aquatica* L. by growing the crop in wild lakes and rivers. As scientists began studying the domestication of the crop to produce a highly functional system, the rice paddy system was developed. Although highly productive in both California and Minnesota, the rice paddy system still contains flaws. Things like disease pressure and seed shattering varieties make the cultivation of wild rice difficult. In order to adjust to these challenges, a recommendation of a hydroponic greenhouse system is made. In the end, the hydroponic system hopes to minimize seed shattering, while allowing for a faster maturation of the crop.

I. INTRODUCTION

A. Study Species.

The crop I have chosen is *Zizania aquatic* L., commonly known as Wild Rice. This crop is native to Minnesota as well as many other regions across the United States and Canada. Traditionally, Native American tribes have cultivated wild rice from lakes and rivers. After the cultivation process began, a rice paddy system was developed for companies and farmers to grow it as a field crop.

B. Taxonomic Classification and Geographic Distribution in the Wild.

Zizania aquatica is the genus and species name for the common wild rice plant. Wild rice has been a staple crop to many cultures throughout the United States of America long before the industrialization of agriculture. *Zizania aquatica* belongs to kingdom Plantae, subkingdom Tracheobionta (vascular plants), super division Spermatophyta (seed plants) and division Magnoliophyta (flowering plants). For further classification purposes, *Z. aquatica* is a member of the class Liliopsida (monocotyledons), subclass Commenlinidae, order Cyperales and family Poaceae/Gramineae (grass family). This particular species is an annual crop native to both the United States and Canada (USDA 2015). Within the United States, wild rice is native in the states of Minnesota, Iowa, Wisconsin, Michigan, Illinois, Indiana, Ohio, Pennsylvania, New York, Massachusetts, Vermont, New Hampshire, Maine, Rhode Island, Connecticut, New Jersey, Delaware, Maryland, the District of Columbia, Virginia, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, and Louisiana. Like in the U.S., wild rice spans across much of Canada as well including the Provinces of British Columbia, Alberta, Manitoba, Ontario, Quebec, New Brunswick, Nova Scotia and Newfoundland and Labrador (USDA 2015).

The plant itself grows in lakes and rivers in water, as an emergent aquatic, ranging from 15.24 cm to 0.91 meters deep in northern latitudes. Although it is native to many southeast states within the U.S. it does not grow as easily there. This is mainly due to warmer temperatures accelerating plant growth, resulting in lower plant height and a lower number of florets. Still, in the northern regions where wild rice thrives, it can tolerate a wide range of water pH (anywhere from 5.0-8.0). As addressed before, flooded fields are necessary to produce this crop (especially in a cultivated rice paddy setting) (Angier 1974). If the seedlings germinate in non-flooded soils, yellowing may occur due to iron deficiency (Angier 1974). The crop may be seeded in the autumn or spring. However, its natural seeding time is in the fall since this seed type is recalcitrant. A recalcitrant seed is one that cannot survive water loss (desiccation) and therefore, germinates instantly (Allaby 2004). Seeding in the autumn also eliminates the need for overwinter storage. For heavy machinery cultivation, autumn seeding is also preferred because of dry conditions compared to spring. The crop grows best in mucky sediment, but grows primarily above the water's surface since it can reach up to 3 meters tall by maturity. *Zizania aquatica* is a coarse plant with long slim leaves, which can range from 30.48 to 91.44 cm long. The upper branches are lush with ovules, while the lower parts of the plant tend to spread and carry microspores (pollen grains). The large plant has a plume-topped grass formation with broom-like clusters of flowers. The annual crop is cross-pollinated because the female flowers emerge first (at the top of the plant) and the male flowers grow lower, shedding pollen after the female flowers are receptive. However, self-pollination may occur if the stigma and anthers occur on the same panicle (Bloom et al. 1997).

Due to its abundance amongst Native American communities, *Zizania* has many common names such as Indian Rice, Water Oats and Water Rice and Mahnomen (meaning "good berry"). Many communities used it as a replacement for potatoes or traditional white rice in dishes such as casseroles, soups, and desserts (pancakes, cookies, and even cereals). The grain is high in protein and carbohydrates and provides a low fat content. When compared to corn and wheat, it has higher levels of potassium and phosphorus (Chapman 1992).

II. CROP HISTORY

A. Breeding & Domestication.

Europeans domesticated wild rice for commercial production around the year 1770, although Native Americans were the first to domesticate the crop thousands of years earlier. The domestication process is much simpler than many other popular crops, as many people began to spread the crop via seed sowing.

The original wild rice domesticators are Native American tribes, specifically the Algonquian and Siouan linguistic groups (Bloom et al. 1997). Many tribes relied on it as a staple food such as the Objibway, Chippewa and Manomini. Long before domestication occurred in the United States a naturalist named Pehr Kalm attempted to introduce it to Europe. Kalm was said to have brought 126 different plant species to his homeland of Sweden after traveling to North America around 1748. However, Kalm's attempt to introduce the crop into Europe failed wild rice, therefore, did not lend itself to domestication (Zilberstein 2015). This led to the main issue when it came to domesticating wild rice: seed viability and dormancy. Since the seed requires adequate moisture to germinate and thrive (it is a recalcitrant seed), many domestication attempts resulted in failure. In 1852, the first person, Joseph Bowron (a Wisconsin native), suggested growing the wild rice as a field crop. Within a year, another man named Oliver H. Kelley from the State of Minnesota suggested the same thing. Efforts to domesticate the crop began around 1950 and within eight years around 48.5 hectares of paddies were being grown in the United States. Small growers began to expand on this effort throughout the early 1960s and by the end of the decade Uncle Ben, Inc. started contracting various hectares (Bloom et al. 1997).

By 1977, the University of Minnesota began to develop a domestication plan for commercially grown wild rice and began a breeding effort focused on more shatter-resistant varieties (Bloom et al. 1997). University of Minnesota scientists are known for developing an excellent paddy grown cultivation system and outstripping the indigenous varieties in production by 1980. This paddy grown wild rice system actually cut Minnesota's wild rice (lake harvested varieties) production down to only 15%. The desire for cultivated wild rice production control became competitive and by 1983, California overtook Minnesota's production by almost 1.58 million kg (LaDuke 2000). Today, many companies in Minnesota, Oregon, Wisconsin and California produce wild rice via paddy cultivation. Some examples include: Moose Lake Wild Rice of Deer River Township Minnesota (http://www.mooselakewildrice.com/), SunWest Foods of Davis, California (www.sunwestfoods.com), St. Maries Wild Rice of Salem, Oregon (Wildriceonline.com), and North Bay Trading Co of Brule, Wisconsin (www.northbaytrading.com) (Bloom et al. 1997).

Figure 1 displays the distribution chain of wild rice in the United States. The domestication of wild rice began with Native American tribes harvesting *Z. aquatica* and using it as a staple crop in their diet. As different explorers and scientists (Joseph Bowron, Oliver H. Kelley, and Pehr Kalm) began to explore the idea of domesticating wild rice for the purpose of cultivation the chain develops (Bloom et al. 1997). Although, some efforts resulted in failure, eventually the cultivation of wild rice drew in the eye of major universities and corporations. Uncle Ben, Inc. began contracting hectares for wild rice production, eventually leading to patent establishment in the late 1990s. Once the attention of major companies was established, the University of Minnesota began and developed a breeding effort for the domestication of the crop (Bloom et al. 1997). Today, California is home to major companies like NorCal who have established significant open-pollinated wild rice varieties that make commercial production a reality (Patent Genius 2011).

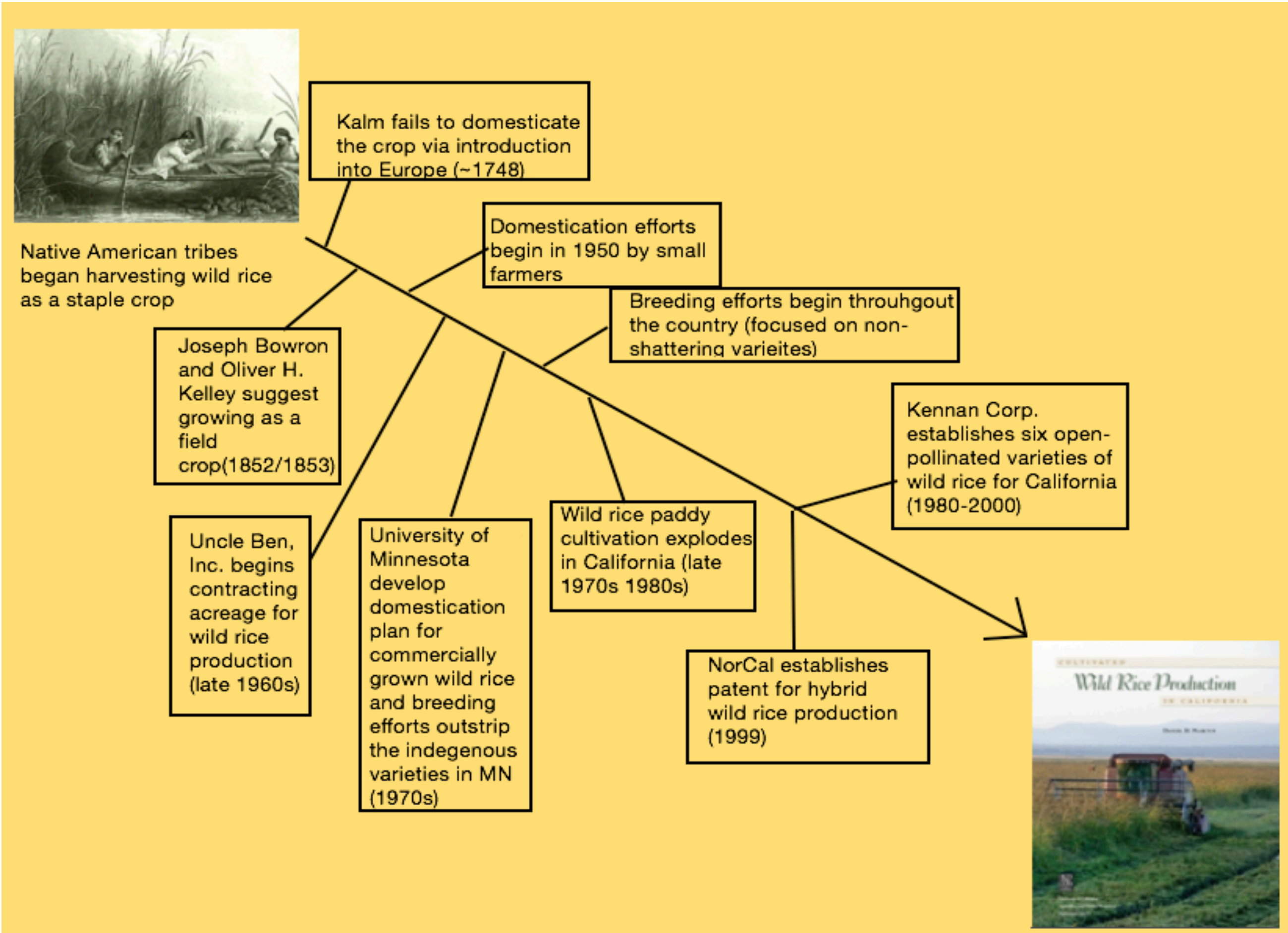

Figure 1. Distribution Chain of Wild Rice (Bloom et al. 1997), (Patent Genius 2011), images: https://en.wikipedia.org/wiki/Wild_rice, http://anrcatalog.ucanr.edu/Details.aspx?itemNo=21622.

III. PRODUCTION INFORMATION

A. Current Production Practices.

For commercial production of wild rice in the field, an intricate paddy system must be put into place. Initially, all brush and small trees must be cleared of the land during the early autumn months (Bloom et al. 1997). For a smaller field construction, a perimeter dike and water outlet must be put into place (small fields are considered to be less than 12 hectares). For the best dike construction, clay soils are important, however, peat soils will also work. The steepest side slope should be 0.45-meters to every 0.30-meter drop. This is important to help maintain ideal water levels for spring germination. Dikes should be no more than 20cm deep (Bloom et al. 1997). Flattening the sides of the dikes may help reduce erosion problems, certainly with respect to peat soils. The primary production method today is seed propagation. In Minnesota, it is important to find a seed retailer that is within 320 meters of the planting site. This helps maintain local varieties, and ensures the seed has been grown in conditions similar to the planting site in previous years. One example of a local wild rice retailer is Moose Lake Wild Rice (as mentioned before) (Bloom et al. 1997). As stated above, for optimal growing conditions *Z. aquatica* should be planted during the autumn season. Seeding may be done by hand or via canoe (depending upon the size of one's field). Most varieties will succeed if planted at a depth of 2.54cm-7.62cm. The seeds must be planted early enough in the fall to allow for at least three months of a cold (vernalization) period. Ideally, three months of 1 degree C weather will break dormancy patterns and allow for an on time spring germination. In total, wild rice may require anywhere from 106-130 days to reach full maturation in the north central regions of Minnesota. To ensure proper germination percentages, *Z. aquatica* should be spread at a rate of roughly 45kg/ha (Bloom et al. 1997).

Once the seeds are successfully sown, monitoring of the paddies is crucial to develop a high yield. The first step in monitoring proper germination is flooding the fields. This flooding technique will allow for proper moisture distribution and circulation of nutrients within the field's soil. Nutrient availability is important for a successful wild rice crop. Generally, nitrogen, phosphate and potassium are the macronutrients of greatest importance. Once the seeds are in place and not covered with mud, the first nitrogen fertilizer application can be applied (Bloom et al. 1997). Liquid applications of ammonium fertilizers, dry urea or anhydrous ammonia are all common fertilizer in the rice paddy industry. It is very important to maximize nitrogen carryover for the following spring season. To prevent oxidation of ammonium forms of nitrogen (to nitrate), fall flooding must be implicated. An additional application of nitrogen can be applied in the early spring before a second flooding of the fields. To maximize yields, up to three topdresses of a dry urea fertilizer should be applied (Eliason et al. 2011). It is also crucial to avoid draining any paddy fields within a week of nitrogen applications. With regards to phosphorous fertilization, many modern day fields rarely face deficiency due to accumulation over time. If needed, phosphorous fertilization applications can be applied in fall or spring. However, these fertilizers must be injected or plowed into a field, so doing so before sowing seeds is important. Potassium is necessary for protection against diseases and high yield in wild rice species. It too can be applied in the autumn or spring months, and is generally applied with phosphorous fertilizers. If phosphorous application is not necessary, potassium may be added to a topdress of nitrogen. (Eliason et al. 2011).

Flooding of the rice paddy fields is important in the autumn and spring to allow for successful germination and nutrient circulation. After germination begins in early spring (late April-May, when water temperatures reach 7 degrees C) the wild rice plant goes into a month long floating stage. During this floating stage, initiated 7-10 days after the emergence of the coleoptile, the radicles emerge and leaves begin to float along the water's surface. During this period, maintaining a constant water level is extremely important. In may production systems, including those in California, changes in the water level may uproot small plants. In addition, if the water depth is increased to cover said floating leaves the stomata on the leaf's surface might no longer be able to take in carbon dioxide for important plant processes (Marcum 2007). As the season continues into late July the stalk and root of the plants enlarge. The floating stage comes to an end when the aerial leaves are produced. By late July, the flowering of wild rice plants begins. Following flowering, the grains begin to develop. This is the key sign to initiate paddy drainage. By early August most fields should have begun the drainage process and many grains will become fully developed shortly after. Ideally, the crop will be ready for harvesting in late August or early September (Marcum 2007).

Harvesting of wild rice is a complex process involving many different methods and practices to obtain the perfect crop. Knowing when to harvest is a major part of this process. Maximum yields are obtained when the harvesting process begins with about one-third of the grain being a green-brown or black color. The consistency of the grain should be that of firm bread dough and have no more than 40% moisture content (Bloom et al. 1997). Commercially, allowing the fields to drain for up to 5 weeks allows for the use of machinery. When using a shatter-resistant variety a combine may be used for harvesting large fields. Many changes have helped to further develop harvesting machinery with regards to the crop due to moist soil conditions. Reels are needed to be seven feet or more in diameter in order ensure the crop is not pushed over during the harvesting process. This type of reel helps reduce shattering and tangling issues with regards to the reeds of the crop. Major companies in California and Minnesota use these commercial techniques (Bloom et al. 1997). However, Native Americans use a much more traditional method when harvesting their crop. The Ojibwe culture uses a technique called “knocking,” which involves canoeing through the open lakes and streams. The tools used are much more basic, such as wooden sticks (“knockers”) roughly 0.9 meters in length. Essentially, the sticks are held outside of the canoe and the harvester brings in as many stalks as possible. The post harvest production of wild rice remains relatively similar with respect to commercial verses traditional methods. A drying, parching or roasting, hulling, and storing methodology has been developed by both commercial and subsistence farmers alike (Manoomin 2015). Commercial processing is done in a processing plant and involves a few additional steps: curing, scarification, cleaning, grading, and packaging. These steps are necessary to ensure the final product is of satisfaction to the wide variety of customers it will reach in the marketplace. For example, the scarification process will allow for a quicker cooking time, satisfying many consumers. In addition, commercial farmers package their crop in warehouses that allow for bulk 45.35 kg sacks to be sold to wholesale producers (Bloom et al. 1997).

The sustainability of the California wild rice industry may be in danger due to recent drought conditions. Although little has been published with regards to wild rice, a variety of news articles can be found online discussing sushi rice (*Oryza).* The rice industry in California is said to be worth 5 billion USD. This is the second largest rice growing state in the U.S. (Arkansas is the first). In terms of numbers, the hectares of rice fields dropped by 25% in the last year due to the drought. By using the resources at hand, one can assume that genetic manipulation of wild rice may allow for less water dependent varieties to emerge. However, this industry is entirely dependent on the paddy system, and without water, no paddy fields can be flooded and no wild rice seeds can be germinated (Associated Press 2015).

B. Current Production Statistics.

Natural strands of wild rice, grown primarily by Native American tribes in the United States and Canada, tend to have much lower yields than commercially grown strands. Combatively, natural strands may produce 90-300 kg/ha, while cultivated strands (in California alone) may produce between 1350-1680 kg/ha (California Wild Rice Advisory Board 2006). Wild rice has long been a specialty crop, grown and sold for a high price compared to traditional white sushi rice. A report conducted by the Minnesota Department of Natural Resources states "During the past 70 years, the price of one pound of unprocessed wild rice has ranged from $0.10 in 1940 to $2.17 in 1966 (MN DNR 2015)." Today, this translates to a harvest of 419 metric tons equating over $12 million. More modern numbers reflect tribal incomes of more than $400,000 when the crop is sold at $1.50 per 0.45 kg. Commercial production in California is still the dominating force today, producing roughly 50% of the cultivated wild rice product in the country. Minnesota is a close second, producing 40% of the commercially cultivated product. As of the year 2000, Minnesota production involves harvesting anywhere from 1814 to 3628 metric tons per year (cultivated and hand harvested) (Minnesota DNR 2008).

Table 1: Variety height and yield comparison of wild rice varieties.

Variety	**Height (cm)**	**Yield (kg/hectare^2)**
K2	Medium (182.88)	Medium-High (2,999.56)
M3	Medium (187.96)	High (1,787.52)
Meter	Short (134.62)	Low-Medium (2,963.56)
Netum	Medium (172.72)	Low-Medium (2,016.32)
Voyager	Short-Medium (167.64)	Medium-High (2,996.79)

Table 1 represents commonly grown commercial varieties in the Minnesota and Wisconsin area of the United States. The sale of wild rice (both price and volume) varies greatly from roadside stands, to gas station sellers, to grocery store providers. In Minnesota, it is easy to find roadside stands or gas stations selling anywhere from 1 lb. to 50 lb. bags of wild rice (0.45-22.67 kg). These low-scale buying operations are directed toward the homebuyer, and are aimed at consumers who want to maintain the integrity of the cultural meaning behind the wild rice industry. Typically, Native Americans will sell wild rice to consumers directly, while major corporations will distribute their products to larger retailers, such as grocery stores. A major company mentioned in the crop history figure shown above was Uncle Ben, Inc. Another major corporate player, based in Pleasant Grove, California, is Kennan Corporation. This company has developed six different open-pollinated wild rice varieties (for production in California) alone. They also claim to be the developers of Uncle Ben's fast-cooking wild rice product, first introduced in 1990. As mentioned before, the scarification technique (post-harvest) allows for this fast-cooking, consumer friendly product (Kennan Corporation 2015). Further descriptions of these accomplishments could not be found, however, contacting the corporation may result in further explanation at a later date. With regards to patents, Kennan Corporation claims to have two US patents for wild rice hybrids and NorCal (another major corporation providing wild rice seed in California) claims to have one patent (Patent Genius 2011).

IV. PROPOSED CROP TRANSFORMATION

A. Crop Production Change(s) for the Future.

Many "do-it-yourself" containerized rice-growing methods have been developed for the home producer. However, these all apply to the traditional sushi rice (*Oryza)*. With regards to wild rice, a containerized approach has yet to be developed. Because wild rice requires adequate cold periods for germination, this containerized approach may be difficult for home growers. In addition, Native American producers object to such practices of using pseudo-energy sources (such as glass house heat and lighting). After researching and developing a production schedule for growing wild rice in the field (paddy system), I find a hydroponics system to be the most environmentally efficient. Genetically, many non-shattering varieties of wild rice are being looked into. Some, already developed, have improved yield in major producing states within the United States. Further research for disease resistant varieties is an important aspect of future commercial wild rice production. Companies like NorCal and Kennan are working currently to develop better varieties each year. Both of these contributions will allow for a better hydroponic system overall. For the purpose of this suggestion it is important to note that these recommendations are based off of studies done on traditional sushi rice (*Oryza)*.

According to a study performed at Chiba University, Japan, optimal rice photosynthetic rates occur at temperatures of 25-30C, with ripening occurring at temperatures of 20-25C (Toru et al. 2014**).** To maximize production, growing inside a plant factory via a hydroponic system is a viable option. This will allow for more than one harvest of wild rice in a single year. A plant factory, or greenhouse, with both sunlight and supplemental light will allow for an increase in production, while maintaining environmental efficiency.

Figure 2: Plant Factory with Sunlight and Supplemental Light (Toru et al. 2014).

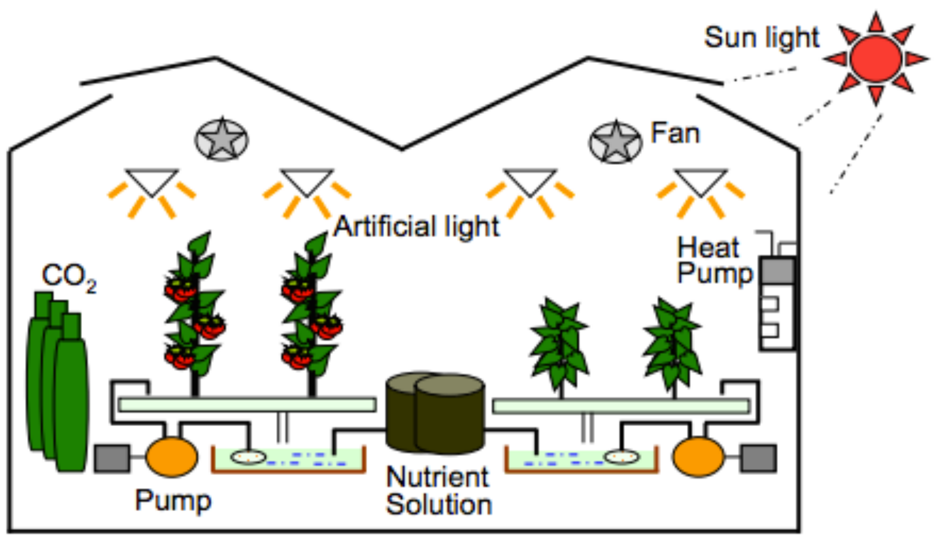

Figure 2 demonstrates a layout of a greenhouse using sunlight and supplemental (artificial) light. The following section will summarize the specific plant production schedule within this greenhouse system.

B. New Production Schedule

Plant seeds initially at the beginning of the May in a growth chamber. Because wild rice typically takes up to 130 days to reach maturation, transplanting the seedlings after germination (into the greenhouse system shows in figure 2) will speed up the process and allow for more production within a given year (Barron et al. 1982). It is best to allow enough time for the seedlings to develop, therefore, transplanting no earlier than 25 days after germination is recommended (Toru et al. 2014). By allowing the seedlings to be transplanted by early June, one is optimizing the natural light and minimizing the amount of artificial light used. This will in turn help lower the cost of greenhouse hydroponic production. A study performed at the University of Minnesota Duluth observed the effects of sulfate on wild rice grown hydroponically and gave the following recommendations for such a media: Hoagland's solution for Ca, Mg, K, etc. at 1/5 strength, 1.1 µg/g N, 0.4µg/ml P as KH_2PO_4, pH buffering to c. 6.5 using TRIS buffer (as opposed to $CaCO_3$). It is important to note that the solution must be changed once the pH falls below 0.5 units (Pastor n.d.). By maintaining the correct pH, the nutrient levels will also be maintained and this allows for optimal plant growth. If done correctly, this schedule will allow for harvest after just 90 days in the greenhouse (Barron et al. 1982).

C. The New Crop Ideotype.

Some of the present challenges with wild rice cultivars in existence are shattering seeds, disease, and slow maturation (or only one harvest per year). By moving the production system into a controlled environment, one is able to closely watch and observe the seed shattering process. Through careful analysis over the course of many harvests, I believe it is possible to minimize seed shattering and create a cultivar that is easier to grow. In addition, disease pressure in the natural environment of a rice paddy system or a pond/river is much higher than in a controlled environment. This will allow for more testing of chemical applications for specific pathogens (for example, fungicides for fungi). Again, by creating more than one seed to seed crop in a year, more testing can be done. Finally, these experiments can eventually be collaborated to ultimately create a resistant, non-shattering variety of wild rice.

V. ACKNOWLEDGEMENTS

Many parts of my paper reference a publication from Purdue University's Extension. This leaflet (online version) helped me grasp an understanding on the domestication, importance, and cultural practices of *Z. aquatica* in great detail. The University of Minnesota's Extension website also provided nutrient management information in great detail. The Wild Rice Production in Minnesota document found from the University Extension Bulletin also provided

valuable information throughout the paper. This document was also cited various times throughout other sources used.

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