Rice in the Northeast: Towards an Ecological Approach

NORTHEAST SARE Sustainable Agriculture Research & Education

By Erik Andrus

Table of Contents

Introduction **3**

Why Rice? **4**

Our Farm's Story 4
Temperate Rice Worldwide 6
The Rice Industry in the USA 7

Northeastern Rice Through the Seasons **11**

Spring 11
Rice Nursery Considerations 11
Managing the Rice Nursery: April-early June 14
Field Preparation: May-June 19
Creating A Rice Paddy 20
Rice Paddy Engineering Techniques 21
Spring Tillage 27
Summer 28
Transplanting - June 28
Looking after the Crop 30
Late Summer 33
Harvest Time - September and October 34
Milling and Distribution 36

Wet Rice Organic Weed Control Trials **39**

Experiment Design 40
Revisions to Design 41
Evaluating Results 42
Further Thoughts on Weed Control 44

Conclusion **46**

Introduction

Rice is a promising crop that is more adapted to Northeastern conditions than often assumed. While both domestically and worldwide, the majority of rice is grown in tropical zones, and in fact the botanical ancestor of rice *Oryza rufipogon* is native to a warm climate in southern China, rice has also been effectively adapted to the temperate zone.[1] Modern domesticated rice, *Oryza sativa,* has two subspecies, *japonica* and *indica*. *Japonica* varieties include the majority of temperate-climate strains, and are the area of greatest interest to Northeastern growers.

Takeshi and Linda Akaogi, in carrying out their 2008 NESARE farmer grant on small-scale rice cultivation and their subsequent publication of the booklet "Rice Growing Manual for the Northeast USA"[2] truly opened the door to the world of temperate rice growing for many growers, including myself. This 2009 publication is still one of the best resources for those considering rice cultivation.

We at our farm began growing rice in 2011 with an intent to build our operations to what I term the "small commercial" scale. This I define as greater than a half acre (at which hand methods alone are fairly viable) but under 15 acres.

There are a number of challenges specific to this scale of growing. The purpose of this report is to outline challenges and benefits to production at this scale.

The first section, "Why Rice?" looks into the history of rice as a crop domestically and abroad and considers the place of temperate rice growing in the context of the local food movement. The second section, "Small-Commercial Rice through the Seasons" will highlight the key phases in rice crop production, with attention to infrastructure, practices, and devices, in order to give the reader a general sense of how a rice farm is created and run. The third and final section, "Wet rice organic weed controls," bears particularly on a challenge we addressed at Boundbrook Farm under a NESARE farmer grant. Weed control emerged as a key limitation, and through our farm trials we were able to weigh the costs and benefits of several approaches.

We are now preparing for our eighth season planting rice. While each new breakthrough and discovery seems to lead to two more questions or problems, it has also been an exciting journey, and it is gratifying to see the method and the public response to it grow. I hope that by

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[1] https://en.wikipedia.org/wiki/Oryza_rufipogon
[2] http://www.uvm.edu/~lhill/ricegrowingmanual%20copy.pdf

sharing our experience the reader can avoid some of our mistakes, and will gain an appreciation of this special grain crop and its potential place in our Northeastern Landscape.

Why Rice?

Our Farm's Story

I came to rice out of interest in other grains. When I bought my farm in 2005 in Ferrisburgh, Vermont I was determined to make a go of it as a grower of wheat and barley. I believed this could be done because farmer Ben Gleason had made a go of it in nearby Bridport on similar heavy soils. To do so is truly accomplishment enough, to do so as an organic farmer even more so, but I also insisted on using exclusively draft horse power.

Several factors converged to thwart my dream of a draft-horse-powered wheat and barley farm. The first is that the number of horses required to pull a plow in soil as heavy as Vergennes Clay is pretty high. Three heavy drafts would tire out pulling a single bottom through it, and would usually end up plowing less than a quarter acre per day. Additionally, even when the land was prepared on time, poor drainage and heavy summer rains frequently would damage the quality of the wheat crop. Over time I became increasingly discouraged with grain growing. Part of the problem was my own inflexibility, insisting on using ancient technology to try to make a living in the modern world, but part of it may also have been the particularly heavy and poorly-drained nature of my clay fields. At least they reliably produced hay and pasture, so I turned my focus to those aspects for a while, but the desire to grow grain didn't go away.

Our farm lies in a very broad and shallow bowl-shaped valley at the head of the local watershed. The bulk of the fields lie down on the flats in the bottom of the bowl, and when water drains from the surrounding low hills and adjoining sloping fields, it ends up on those flats, eventually draining off to the north towards Lewis Creek. But there is so little pitch, it takes a long time to do so. Sometimes, after a very heavy rain, we might see a big lake, probably a foot deep at most, covering some acres of land down on these fields. My wife and I would look out the window and say "we ought to be growing rice!"

"We ought to be growing rice!" was something dairy farmers in our area might say, usually in an irritated and sarcastic tone, when corn and hay fields were flooded throughout the county. This phrase was basically a way of saying that farming conditions in general were pretty terrible.

For me the idea of fields of rice instead of hay or corn wasn't inherently ridiculous. I had lived in Japan from 2000-2001 and saw there that growing rice in a place like Vermont was actually a possibility. I lived in Sendai, on the northern part of the main island of Honshu, and in the areas around Sendai in Miyagi Prefecture you could see rice being grown everywhere, despite it being a very temperate climate similar to that of New Jersey. I had also toured several farms in Miyagi, most of which produced rice as well as vegetables or another specialty crop like flowers or mushrooms. It was clear to me at the time that the Japanese really had their act together for growing rice, in terms of their tools, methods and infrastructure and general level of organization. But unfortunately, even though back then I considered myself to be a farmer-in-training, I didn't pay as close attention to Japanese rice farming as I could have done, because I didn't believe back then that it would ever apply to my own future as a farmer in the Northeast. While I realized it could probably be grown in my home region, I didn't realize that I would actually want to do so. I assumed my future held more traditional Northeastern crops.

Fast forward from that time to around 2009, when frustration with my wet, heavy clay farm was building, and I wished I could revisit that world and give temperate rice a try. But I really didn't know where to begin, and didn't have any connections from my earlier time in Japan to draw upon.

Then I heard that there was a farmer in southern Vermont who was addressing that very question--how do you begin? In February 2010 I attended Takeshi Akaogi's workshop on rice growing at the NOFA-VT conference in Burlington, Vermont. I was totally hooked. Here was a way to make my problematic farm produce and bloom.

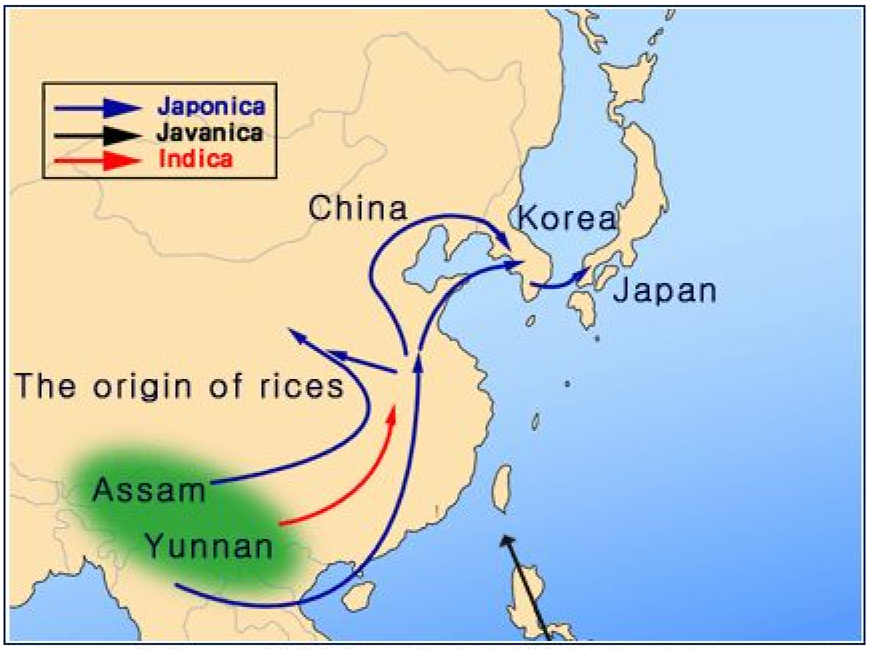
In the spring of 2010 we hand-dug two small paddies, about 15 feet square each, and planted 400 or so seedlings grown from 5g seed accessions from the USDA germplasm reserve.

The path from that moment of clarity to actually operating a farm that operates even half as effectively as your average Japanese farm has been long and bumpy. The situation with rice growing here is vastly more challenging than it is in Japan, where ample resources exist to support every aspect of growing, and the local base of experience is vast. Here in the Northeast, growers must largely figure out solutions on their own without any institutional support and without the benefit of long experience. It is a daunting challenge, and not for the risk-averse.

However the payoff is, I believe, worth it. Once established, rice has one of the highest returns on energy invested, for a cereal crop. Being grown in a zero-erosion paddy environment, it is very nutrient stable. The growing environment improves the retention properties of local watersheds and creates vast new habitat for wildlife. And the product is delicious and prized among local and regional buyers.

Temperate Rice Worldwide

Based on recent archaeological finds, rice is believed to have been domesticated in the Yangtze River Valley about 15000 years ago. By the third millennium BCE, rice cultivation was rapidly expanding in China and throughout southeast asia. By approximately 400 BCE, rice cultivation had expanded to mild temperate areas of Asia including northern China, Korea, and Japan.



Introduction of rices to Korea based on the Gene Center Theory

[3]

By this point in history rice was being adapted to progressively more northern zones. While in a tropical environment two or more crops of rice might be produced in one year, in the temperate zone only a single crop is possible. As rice moved north early rice farmers developed techniques and landraces of rice that allowed for this.

The practice of growing seedlings in a more intensive, protected setting and transplanting them out to wider spacing in a larger field

Growing rice into zone 5, which describes the area in the Northeast from Northern Pennsylvania and also northern Honshu and the island of Hokkaido in Japan might be quite difficult without advances in plant breeding and in season extension, and so was not undertaken until recently. Rice growing didn't even move into the island of Hokkaido until the early 20th century, as a

[3] National Institute of Crop Science (Korea) www.nics.go.kr

modern agricultural development scheme undertaken by the Japanese government with the support of agronomists from the University of Massachusetts. Japan has subsequently invested considerable resources in developing methods, devices, and cultivars for temperate rice. With rice growing area greatly limited and subject to development pressures on the more southern islands, Hokkaido has become Japan's leading producer of rice.

Temperate rice is also grown in the Ukraine area, and several proven rice varieties, including duborskian, omirt and successfully adopted in the Northeast originate there. Like the Japanese adaptation of rice to colder growing zones, Ukrainian rice system development did not occur until the early 20th century. Today in Ukraine, rice is planted to about 38,000 hectares annually.[4]

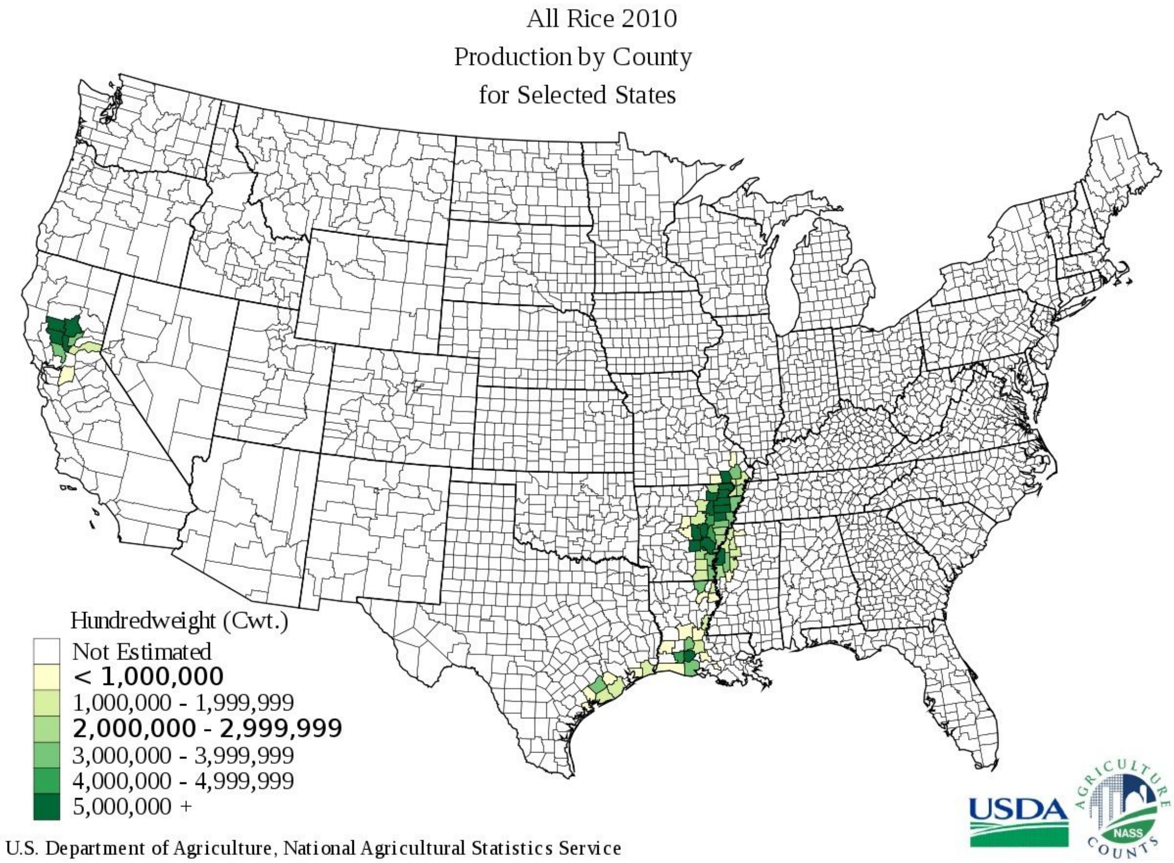
Being that growing conditions are similar and the plant varieties themselves are borrowed from the rice agriculture of these places, it is of enormous benefit to adopters of rice here in the Northeast to study the practices, past and present, of rice farmers there. Given my past exposure to rice growing in Japan, I have tended to focus my research there. Further research into rice practices in Korea and Ukraine would be of great benefit to the Northeast's small but growing group of rice growers.

The Rice Industry in the USA

Rice growing in the Americas began with the earliest European colonists, and was documented in Virginia in 1609. While not the preferred food source for European settlers, rice plantations were created to feed slaves, who were familiar with African rice cultivation and cooking. The Madagascar cultivar Carolina Gold (oryza glabberima) dates back to this period, and this variety is still grown to a limited extent in that area today, and to a greater degree in the South.[5]

However the two principal rice growing areas are the south-central US (Louisiana, Alabama, Arkansas, Missouri and Texas), and Northern California's Central Valley as shown below.

[4] http://ricepedia.org/ukraine
[5] http://www.carolinagoldricefoundation.org/



[6]

In order to be plotted on this USDA map in any shade, counties produce at least 50,000 tons. At the rate that Northeastern rice operations are developing and growing, it may be a long time before any county merits the lightest shade of green! This map is a window on the nature of most existing US rice production: it is very large in scale.

Industrial rice growing is supported by a USDA research establishment as well as state extension services in the states where it is grown. The vast majority, if not the entire focus of these institutions is commodity production, primarily for export. Although the USA produces only 3% of the world's rice, it is also the 4th largest exporter.

Rice agriculture in these areas is generally very chemical and equipment intensive, and methods are commonly used on large rice farms in the South and California would generally be totally out of the question for Northeastern small-scale growers, for instance the use of aircraft to disperse pre-emergence herbicide into standing water and for the subsequent sowing of rice seeds and spreading of fertilizer. Additionally, the warmer climates of these growing areas mean that methods and varieties will generally transfer poorly to the Northeastern setting.

[6] USDA, National Agricultural Statistics Service, 2015

Photo: LSU AgCenter Rice Research Station, 2011
http://lsuagcenterrice.blogspot.com/2011/04/

Above: rice harvest in Arkansas. https://youtu.be/KeQmA24dXQk

Given the differences in landscape, support resources and market focus, there is only so much that can be carried over from rice growing operations elsewhere in the USA.

However Japan presents an interesting alternative model for rice agriculture that is worth the attention of Northeastern growers. There, as here, farm size is limited by geography, and is also subject to development pressure and is often expensive. Farmers have limited labor resources (a typical Japanese farm is run by a couple in their 50s or 60s with little hired help). Farmers are also often quite resourceful in reaching markets directly when possible to maximize value-added revenue and customer loyalty, and Japan has devised many sales mechanisms akin to the CSA concept to those ends. While rice agriculture in particular carries a certain national prestige and support--Japan's government maintains a strong protectionist stance against imports with quotas and high tariffs--farmers are also working in small groups or as individuals to cultivate support at the community level.

Additionally, although Japan's agriculture is fully modernized and involves the use of chemical inputs, there is also a movement away from this practice and towards a more organic, holistic practice of rice agriculture. This has led to several movements in the field of rice growing, including that of "aigamo," or "duck-rice agriculture." Farmers and farming organizations strive to reach a clientele that is committed to this kind of food and farming and to receive better compensation for their practices, a situation that parallels the organic food movement and affiliated food trends in the USA.

Japan's trend towards small scale and community focus certainly has similarities to the situation in the Northeast. So to does the existence of small farmers there putting in extra effort to farm without chemical inputs. Lastly, the fact that Japan also has rice agriculture adapted well into zone 5 growing conditions, I tend to look to examples there when I encounter challenges as an early adopter rice farmer, far more often than I look to resources with my own country.

I believe that eventually, if and when rice takes root as a crop in the Northeast we will develop our own distinctive way, or perhaps many distinctive ways, of growing it. Surely it will take quite a bit of time and effort and a good dose of missteps and failures along the way. For my own situation, as of this writing, I feel the challenge of growing the crop is too steep to permit me great creativity with it. Generally, I strive to know the Japanese way as completely as possible, and then to adapt it to my own context as well as I can do. This problem-solving approach has allowed me to begin to bridge the gap between the horticultural-scale methods presented by Takeshi and Linda Akaogi in 2009 and the beginnings of small-commercial growing.

Next, we will follow our rice practices through the seasons, describing our most recently adopted practices. As we go I will sometimes compare with common practices in Japan due to the strong influence of things I've learned from Japanese rice agriculture (and from aigamo agriculture in particular) on our own operations here in Vermont.

Northeastern Rice Through the Seasons

Rice is a long-season crop with special management considerations. This section is intended to supplement readily available high-quality resources in English for rice growers, including the original 2009 Akaogi Rice Growing Manual available from NESARE, the book A Farmer's Primer on Growing Rice [7] and the IRRI online knowledge bank (www.knowledgebank.irri.org). These resources provide little guidance for small-commercial practices for temperate region growers. Particular attention will be given to topics for which resources are otherwise unavailable, notably nursery management, weed control, and postharvest processing.

Spring

Rice Nursery Considerations

The rice season usually begins with planning the rice nursery. Raising healthy rice transplants is the first challenge of the season, and in this phase most variables are under the farmer's control and take place within a smaller space and over a fairly short span of time. Most growers who have raised vegetable starts with the benefit of frost protection should be familiar with the basic principles of managing the rice nursery.

Where rice seedling production is different from vegetable production is in the short duration of the production and the large quantity of growing area required.

Most rice varieties I have worked with require at least 150 days from planting to harvest. This means that cold may be an issue at either end of the season, either impacting seedling production or ripening. While ripening plants are less vulnerable to cold damage than young seedlings, seedlings can be grown despite low temperatures given the right facilities and techniques.

In Japan, I have seen quite a lot of hoophouses being used for rice. These are usually very large basic season extension structures that are stripped bare in winter in very cold and snowy areas. They have no benches and usually no permanent watering infrastructure. They are also generally unheated, as the baseline thermal gain is adequate for germination and seedling growth and the risk of cold snaps in a maritime climate like Japan's is low.

[7] *A Farmer's Primer on Growing Rice,* Benito S. Vergara, 1992, IRRI, Manila, Philippines

Hoophouses and low tunnels are both good choices for the Northeastern seedling operation, in that they provide a lot of growing area for a minimal investment. While a fully equipped and heated greenhouse would surely be ideal, the annual cost might be difficult to bear for a crop like rice that requires so much growing area per unit of production.

Here at Boundbrook Farm, I have used both low tunnels and hoophouses. I have also used multiple watering techniques. Most recently in 2017 we used low tunnels set in a nursery paddy that was meticulously leveled before setting out the trays. Next year we will be moving to a more standard Japanese-style arrangement, with a large dry-floor hoophouse.

The advantage of low tunnels, covered with ag fabric is that this system is extremely affordable. While it provides a basic thermal buffer against cold (usually gaining about 10-15 degrees during the day and about 5 at night, it is not prone to overheating on sunny days, a problem we once had with a clear plastic sided hoophouse. When the trays are precisely set in a flooded paddy, they are uniformly watered from the bottom up. Watering is accomplished by bringing the whole nursery paddy to the appropriate level, for instance with a garden hose. There is no need to water the trays from the top individually.

The disadvantages of this system include being very time-consuming to install (as each tray must be wiggled into the mud to get just the right level) and also troublesome and inconvenient to work it. On occasions when the sides needed to go up or down, this could only be done by wading through the thick mud between the low tunnels. I left just a 1’ wide walking area between each tunnel and the next.

One year we raised seedlings in low tunnels set on dry ground, not in a paddy. The advantages of this include easier site preparation (and sloping ground can be used, too) and easier walking between the low tunnels to service them. We watered by lifting the fabric and watering with a hose twice a day. But the extra demands of watering are the key disadvantage--as a paddy stays reliably and uniformly wet, it requires only infrequent watering. The dryland low tunnel nursery however was a lot of unnecessary work, and, given the high airflow through the low tunnels and the small amount of seedling soil, the seedlings were prone to drying out especially on hot and windy spring days. We tried this once and never repeated it. A good seedling raising system will have consistent moisture and will have good safeguards against drying out. However, it is possible that drip irrigation could be a good fix.

For all of our low tunnels, we used two grades of agribon brand ag fabric, a heavier one and a lighter one. We usually removed the heavier one for good around May 10th. It is good to have heavy material around to cover the tunnels in case a serious cold night comes up. It is not worth taking chances with rice seedlings, as any loss is really not recoverable and can easily impact the entire season.

When moving to a high-tunnel (hoophouse) arrangement, the advantage of having a flooded paddy-style floor is reduced, and it is easier to fully utilize and work high tunnels if the floor is firm with either no walkways or just one narrow walkway. This could be impractical with a paddy-floor hoophouse, in the event that any trays needed particular attention. Instead, growers usually line the high tunnel floor with plastic, and accomplish watering either with drip irrigation below the flats or with watering from above. Various different kinds of above-watering systems can be found, from overhead nozzles to an automated watering machine with booms projecting from a central unit that runs down the hoophouse on a sort of railway track, to simply watering with wands through the roll-up sides or by walking down the center isle.

Next year we intend to use the drip tape approach. Whatever approach is used, the grower needs to watch carefully for dry spots. While rice seeds can usually germinate adequately through standing water and fully flooded soil, the best conditions for germination and sprouting seem to be warm and damp yet not flooded. If rice must reach through any depth of water before reaching the surface, the seedlings seem to be weakened as a result.

It is equally important in any event to closely monitor hoophouse temperatures, keeping them in the 60-90 degree range as much as possible. While freezing is fatal to seedlings, temperatures below 60 are not conducive to growth, and if they persist for days, may lead to the onset of mold damage to developing seeds. During the nursery phase I monitor the nursery temperature manually and electronically. I use a weather station with a probe that I can put in the nursery soil that transmits to a unit in my house. This way I can easily keep track of the nursery even while busy with other tasks. With this stream of information, plus the weather forecast, I can usually stay on top of nursery management and keep ahead of changes in the weather.

Anyone considering rice as a crop should carefully consider what nursery designs and strategies will work best for their location to maximize growing warmth in April and May, ward against freezing damage, make efficient use of labor, and deliver the best performance for the investment.

Type of Nursery	Cost	Ease of working by hand	Ease of working with equipment (forklift, tractor)	Frost protection quality
Low Tunnel, Paddy Floor	cheap	avg	hard	avg
Low Tunnel, Dryland floor	cheap	hard	avg	avg
High Tunnel, Paddy floor	medium	hard	hard	good
High Tunnel, dryland floor	medium	easy	easy	good

Greenhouse, heated	Very high	easy	easy	best

For growers who intend to plant by hand, it may be worth using cell flats with a small cell size, if a way can be found to seed and prepare these efficiently. After our first year, we have been using open trays that are made to use with mechanical rice transplanters. However you can also raise seedlings for hand transplanting in any open tray. These trays are just under 1' x 2' in their outside dimensions, making them roughly comparable to domestic trays and easy to plan for when laying out the nursery.

The following table provides some guidelines for nursery planning.

	Single tray	Per Acre (130-140 trays)
Tray space requirements	2 square feet	260-280 square feet
Seed Required	.20-.4 lbs	26-52 lbs
Paddy coverage	300-330 ft 2	42000 ft 2
Number of hills when transplanted	300-500	42000 - 60000
Quantity of nursery soil	0.15 cubic foot	0.72 cubic yards
Labor required, manual method	5 minutes	12 hours
Labor required, nursery machine	1 minute	2 hours

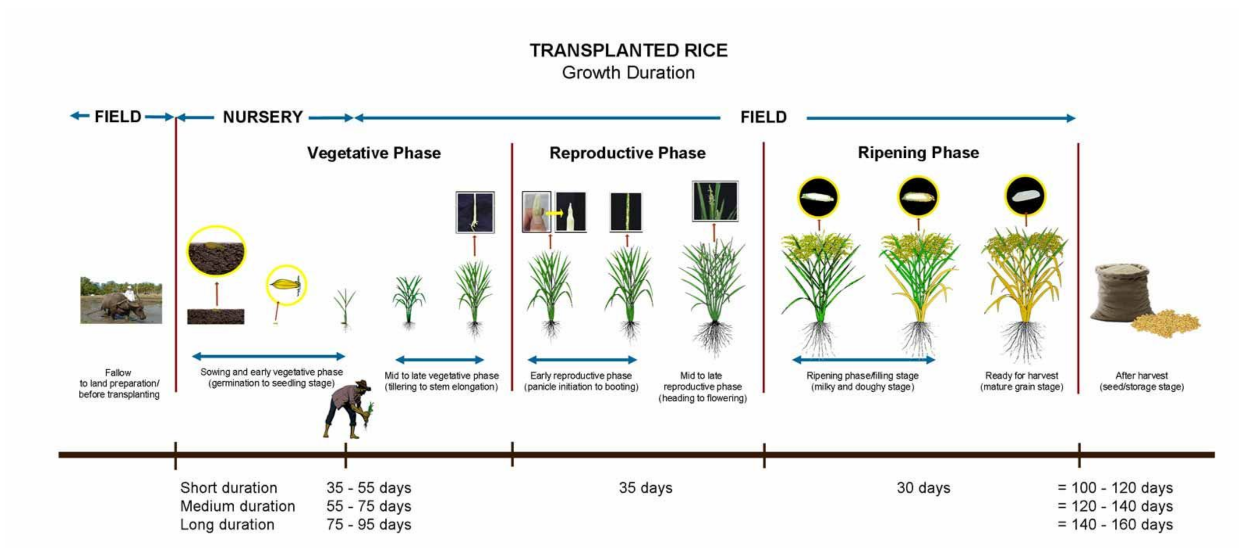
Once you have planned the scope of your transplanting and designed your nursery system to match, you can prepare it to receive flats in April.

Managing the Rice Nursery: April-early June

Beginning to rouse your stored rice seeds from dormancy is the first step in a chain of events that will, with luck, carry you through the growing season to harvest time. The time of year you begin should be carefully considered. For the shortest-season varieties, like Hayayuki, there may be more leeway to delay planting. For longer-maturing, longer season varieties like Koshihikari, there will likely be greater urgency to get an early start in order to finish the season before cold sets in.

Most rice varieties that I have worked with range from 140-170 days total from initial planting in soil to harvest. Transplanted rice takes longer to mature than direct seeded rice by 10 days or more, but adds a dimension of technical challenges beyond those of transplanted rice. The primary reason to raise transplants is to maximize the growth differential between the rice plant and the weed competition. Traditional rice systems universally grow transplanted rice to obtain this benefit, and on our own farm we have never felt confident that we could do without it either.

Transplanting rice using technologies and approaches available to small farmers is certainly doable on a commercial scale. If executed correctly, great labor savings can be realized. It is only possible to direct seed if one can precisely cultivate around the sprouting and growing rice seedlings twice with the use of ducks, or several time without. Having never tried it, I can't really address the challenges of using this method yet.



[8]

Once you have decided what day to plant in soil, begin soaking the seeds in cold water 5-7 days earlier than that. Change the water daily. Discard any seeds that float. 24 hours prior to planting, put the seeds in 80-90 degree water, and maintain that level of warmth as best you can. This bump in temperature will stimulate sprouting.

Seeds should be planted shortly after sprouting before rootlets become long enough to be damaged during handling.

For open flat seeding, I lay about ½" of rich nursery soil (about ⅓ compost, ⅔ topsoil) into the tray and use a concrete trowel to make a uniform, firm base layer. Then I sprinkle seeds over the base soil to ensure that there are about 10 seeds per square inch at minimum, and a whole

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[8] IRRI Knowledge Bank, http://www.knowledgebank.irri.org/

single layer of seeds at maximum. The standard Japanese rate is 150 grams per tray, or about 5 ounces.

Generally for hand transplanting use, a sparsely seeded flat is fine as this will have fewer, larger seedlings and will be easier to pull apart when transplanting. Flats destined for use by a rice transplanter machine want as dense of a mat as possible, in order to form mats that can be handled easily and to avoid bare spots in the tray which will result in the transplanter planting irregularly.

Once planted the seeds are covered with another ¼" of soil and thoroughly watered. After this the trays can be stacked up to 20 trays high and covered with a plastic sheet and left in a warm area for another five days or so. Daylight is not necessary. The soil will remain moist for that duration. I usually check the trays daily, and try to look at ones in the center of the stack as well as the top. When the seeds begin to emerge, the trays need to be swiftly moved to the growing location before the sprouting tips press against the underside of the flat above them and become distorted. This usually occurs at the five day mark. Using this method of incubation is a way to get maximum development without the risk of placing the trays in the outdoor nursery. In the meantime, spring is progressing and the days are hopefully becoming warmer!

The earliest I have ever begun planting is April 5th, and the latest was around May 5th. Now I have settled into a pattern of planting into soil between April 15th and 20th, which for my location is a good balance between the risks of a cold spring and the risks of a cold fall. The actual date that the trays get moved to the seedling nursery would be between April 20th and April 25th.

Once laid out in the nursery, the plants will begin to grow. Bear in mind that while frost or freezing will kill your plants, any conditions that are anywhere below 60 degrees will not do them any good. Rice is a tropical, warmth-loving plant (even the cold-tolerant varieties) and will thank you for every effort you can make to keep the growing environment between 60 and 90 degrees. Very hot temperatures are not so great either and can lead to yellowing and wilting. The nursery therefore needs constant monitoring to ensure that neither dryness nor temperature extremes nor driving rains nor wind nor unwelcome animal intruders threaten your crop at this delicate stage.

On the last point, birds are powerfully drawn to rice flats and can do great damage to them by plucking the seeds out of them. The flats therefore need to be kept secure at all times. Likewise rodents including chipmunks, rabbits or rats can also be problematic. Vigilance is the key.

Once the seedlings reach a height of three inches or so, most of the starch in the seeds is consumed, and the risk of animal damage is somewhat lessened. This occurs at about the 30 day mark.

In general, transplanting earlier is advantageous in that the plant has more time to adapt to its field growing location and to take advantage of a non-crowded full-sun growing environment. However, transplanting too early can result in weed proliferation, since water depth must be very low to avoid drowning transplants for a prolonged period of time. In general seedlings should be no less than 6” tall with three full leaves and can be grown up to 10” tall.

Taller seedlings may take longer to root and grow after transplanting and it is likely that transplanting oversize seedlings has some impact on yield. But this in my opinion is outweighed by the ease of weed control in fields transplanted with large, sturdy plants. In order to raise seedlings to such a size, even with a rich nursery soil base with plenty of compost, additional fertility will likely be required, especially nitrogen and phosphorous. A tea of fish or kelp for watering is a good organic approach. Soluble fertilizer can also be broadcast and watered in to the flats.

Nursery types that have a completely level paddy base can be flooded completely so that the soil is completely saturated once all seeds have sprouted, but overflooding before seed emergence can result in weak, delayed sprouts that have to struggle to emerge from underwater. The best environment for rapid emergence is wet, but is also warm and aerated.

Above: low-tunnel style nursery with paddy floor base. This type of nursery is economical and reasonably effective, but is labor-intensive to set up and inconvenient to work in.

Also bear in mind that if seeds in the process of sprouting are subject to cold conditions (under 55 degrees) for any length of time, seed molds may set in. These molds attack the starch in the seeds. The best countermeasure is to drain excess water and warm the growing environment by any means available. I have devised systems to heat batches of irrigation water with a wood fire, and am in the process of building a dry floor hoop house that will use a large kerosene heater for emergency heating. Hopefully cold snaps won't occur, and if they do occur, won't last, but having one come at an inopportune time can be disastrous for the rice nursery and it does not do to leave it to chance and be unprepared.

Once seeds are fully sprouted and growing, mold is less of an acute concern, but cold will still slow seedling growth considerably. The nursery phase is where rice growers need to be mindful that rice is at heart a plant of the tropics, and the better we can make it comfortable in the nursery phase, the better of a start we will have towards a successful season.

Above: By the first week of June the light covers can come off the nursery for good. If we think it might be necessary to redeploy covers, we leave them furled up along the tops of the hoops.

The most demanding part of the nursery phase is the preparation of the flats and the initial setup. If watering and temperature control are reasonably well laid-out, routine maintenance after that point is not demanding. As the nursery period comprises five or six weeks, this allows the farmer plenty of time to prepare the paddies while still keeping a close eye on the nursery.

Field Preparation: May-June

Here at our farm we subscribe to the usual way of growing rice, in a leveled, flooded paddy. This is the manner in which the vast majority of the world's rice is grown in both traditional and modernized systems. Although creating a paddy system entails a heavy initial investment, there is a solid payback over the long term.

While *oryza sativa* can be grown in a dryland setting like other grasses and cereals, it is likely that yields won't be as high as with paddy agriculture. Additionally, unless the field is very well-watered for the first part of the growing season, the plants can easily dry out and die. Farmer Nazirahk Amen in Maryland grows several varieties of rice in a dryland setting using drip irrigation. Christian Elwell of South River Miso in central Massachusetts had also grown duborskian rice for many years in a dry setting, but then switched to a paddy and experienced a near doubling of yield. It's my opinion that creating a rice paddy is well worth the benefits, of which yield is only one.

A second benefit is the proven nutrient retention properties of the rice paddy. A rice paddy is a totally level field base surrounded by a low berm. Even if the soil is bare, rains cannot rip through the field creating gullies and carrying away topsoil because there is no slope. Even if rain falls into the paddy and accumulates inches deep, it cannot go anywhere because of the berm. Even if a massive rainfall occurs and the water level crests the berm and overflows the paddy, erosion damage will still be minimal because the water will be sheeting slowly over a flat area rather than tearing through a narrow one. It is largely because of these attributes that terraced paddy agriculture has such a long and stable history in Asian civilizations.

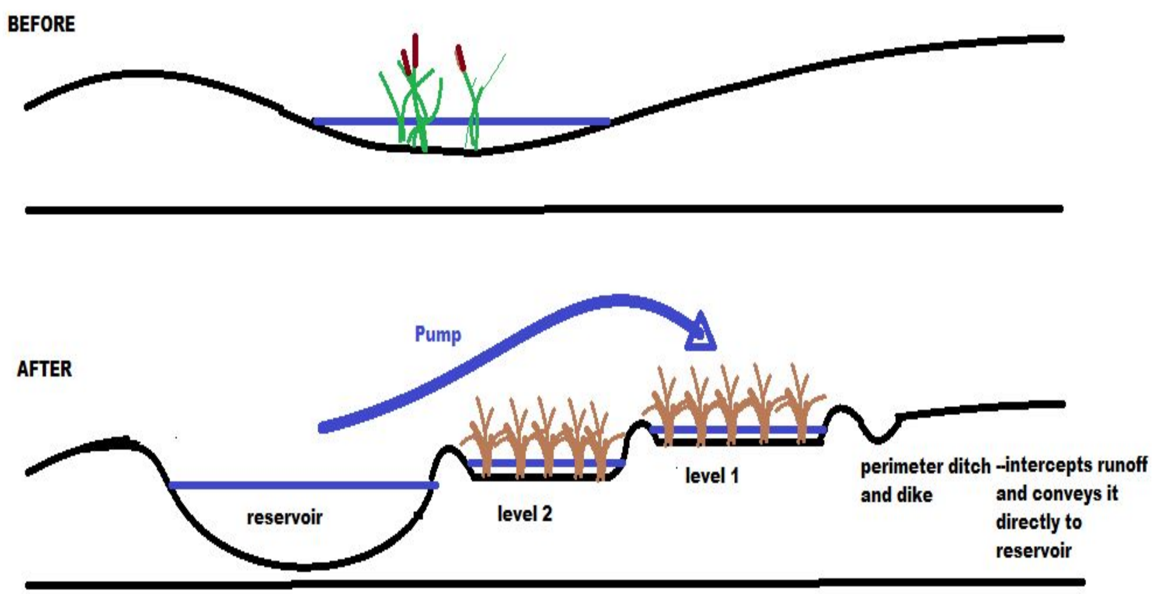
I have heard that the water element in rice paddies is what explains the fact that rice can be grown in the same location for many years without crop rotation. The water forms a kind of barrier between the growing plant and the soil where pathogens might develop, and the water itself is constantly being exchanged and refreshed. I am not sure what the scientific merits of this explanation are, but crop rotation is of minimal concern in wet rice agriculture.

Creating A Rice Paddy

A rice paddy is a flat, water-retaining field surrounded by a low berm. There also need to be provisions to add water at will and to drain water away at any time with minimal effort. Site design involves a balancing of several factors in order to integrate your rice system well into the surrounding hydrology and topography and to maximize its ease of use and maintenance for the grower. Each paddy we have created here has taught us lessons and shaped how we approach subsequent engineering challenges.

It is important to understand that rice systems are isolated from the hydrology of the land around them to a great extent. Ideally surface runoff would not run into or through rice paddies, although it might run around them into a holding pond, or into them in a controlled way from a holding pond at a higher elevation. If standing water does form on the land adjoining a rice paddy during storms, the berms surrounding the rice paddy should be high and strong enough to prevent runoff water from overflowing into the growing area. This prevents flash runoff from overflooding rice paddies during storms.

There must be a reliable water source through at least early August and an easy way to move that water in the volumes required. In our case there is no waterway with the flow required, so we have created holding ponds that fill in winter and recharge with surface runoff water at intervals during the growing season. We have found 50,000 cubic feet of water storage per acre to be adequate for all but the dryest growing seasons. In our case we have our holding pond at an elevation lower than the rice paddy, and we must pump the water up from the pond to irrigate the paddies. In other cases it might be practical to have the pond at a higher elevation, allowing gravity flow into the rice fields.

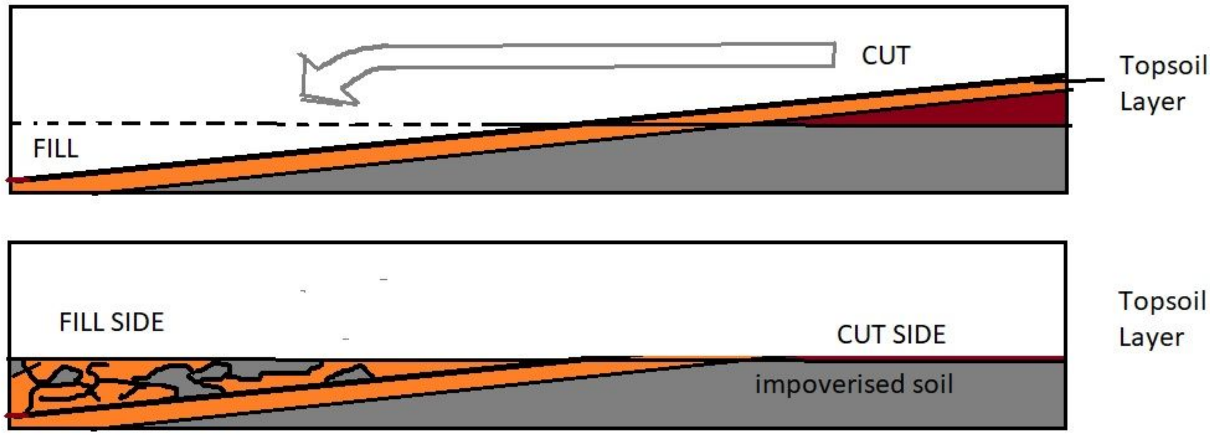


Above: principles of rice paddy design, illustrated. A natural, undulating, unevenly wet landform is altered to create two levels of growing area, a reservoir pond and a perimeter ditch to isolate the growing area from the surrounding hydrology. A pump moves the water to the rice plots, but they can gravity drain into the reservoir when needed.

Rice Paddy Engineering Techniques

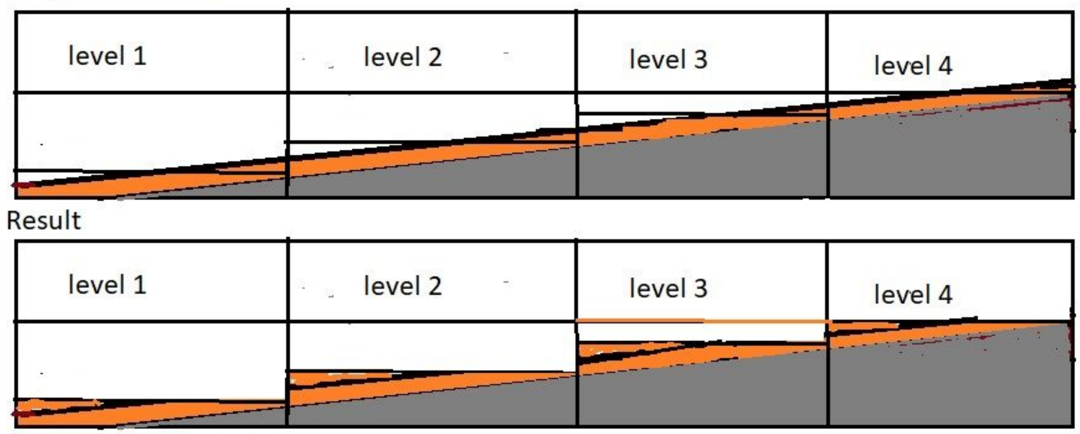
The basic cut and fill method involves moving all soil profiles from the high side to the low. Depending on topsoil depth, field slope, and size, this can result in the cut side being badly stripped of topsoil, requiring substantial future amendments.

Basic method



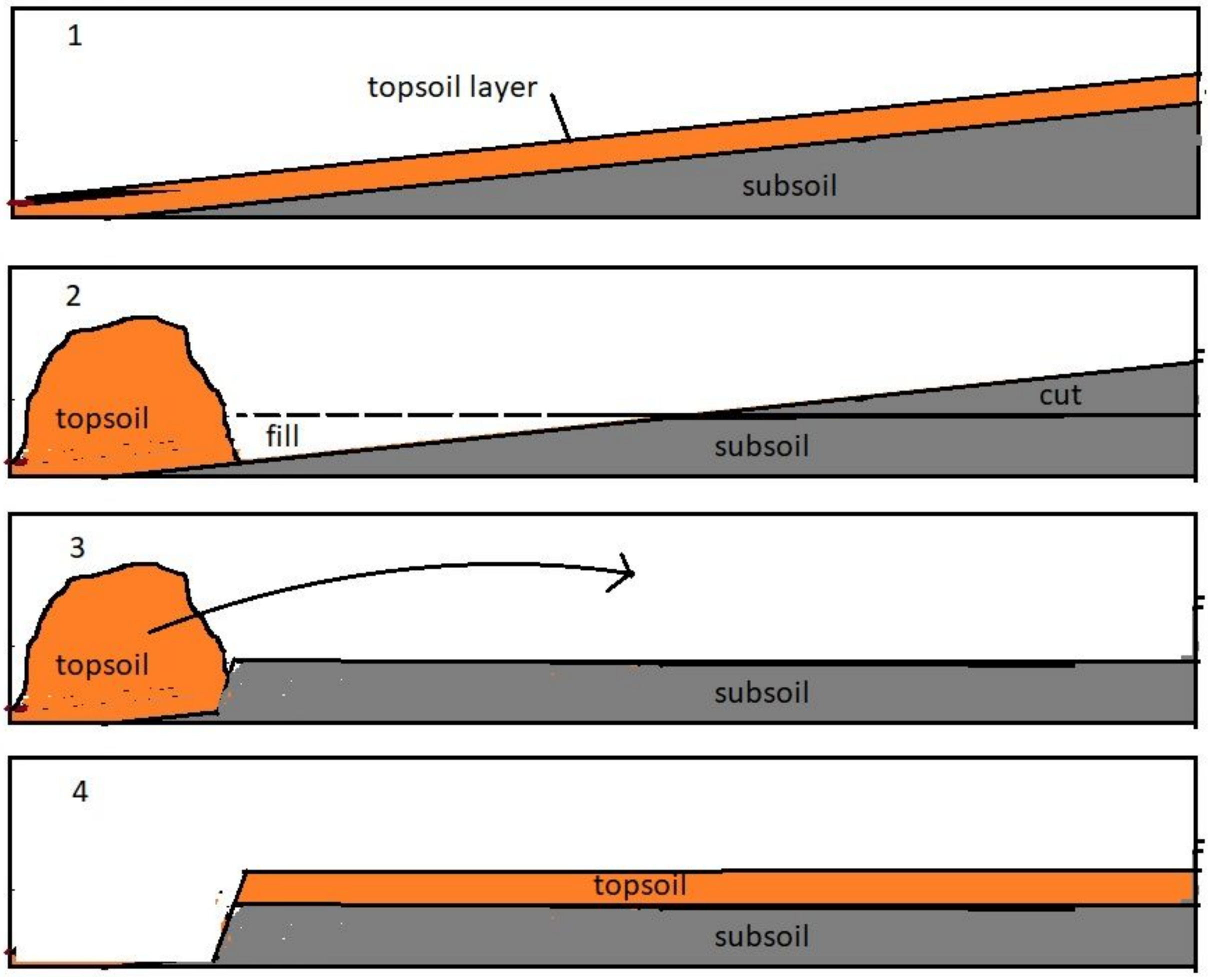
An improved method involves multiple levels of cut and fill, in order that at least some depth of topsoil is maintained on the cut side of each tier.

Improved method



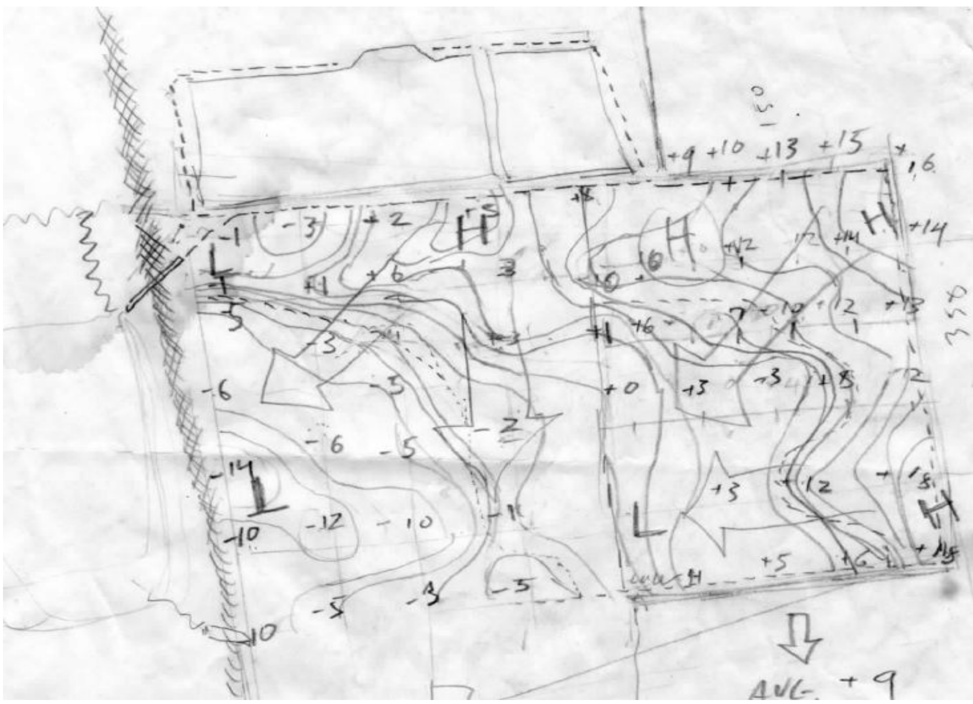
The best method involves removing all topsoil from the site to be leveled and setting it aside. The topsoil is redistributed over the leveled subsoil. This involves the most work but yields the largest, most uniformly fertile final result.

Best Method


1
topsoil layer
subsoil
2
topsoil
fill
cut
subsoil
3
topsoil
subsoil
4
topsoil
subsoil

The general principles of rice design are fairly simple. The rice grower wants the largest level area possible with the least amount of soil disturbance and earthmoving. To this end, to one degree or another, the topography of the starting landform must be taken into account.

We begin our site design process by doing a detailed elevation survey of the site. This is best done with a transit and surveyor's rod, or with the modern version, the rotary laser transit. By laying out a grid on both the site map and on the land itself, with markers or strings to mark out the grid, an elevation can be taken at each vertex and transcribed to the site map. We start with what we guess is an average elevation for the whole site and mark deviations from that in inches as our elevation, for instance, -2, +4 and so on. On the final map this collection of numbers lets us make a topographic map of great detail.



Above: site elevation for approximately 3.8 acres. Layout was at 50 foot intervals. The elevation differential over the whole site was 30", which was too much. Once divided roughly into quadrants the differential was only about 15", meaning the maximum cut would be only about 7.5".

The basic process of creating level ground can be described as "cut and fill," which is to say that material is cut off of the high side of a parcel and moved to the low side to raise its elevation. Given that we're creating a field and not a parking lot or airport runway, there is a clear downside to this approach. The side of the parcel that is being cut will be the clear loser of fertility in any soil type, and some degree or another of soil amendment will surely be required before it is the equal of the filled side, which received all or most of the topsoil. The larger the field, the larger the cut is likely to be, and the worse the disparity of fertility.

One way to minimize the unequal distribution of topsoil in the final rice paddy is to remove all topsoil from the leveling site and redistribute it equally after the subsoil has been leveled. This adds considerable work to the project of creating a rice paddy but could be worth the effort in some cases.

We use machine processes in our field work and so we were not content to have very small paddies of 1/10th of an acre or less. It would be too inconvenient to work even small rice farming machinery in plots so small. Therefore, to excavate fields of up to 0.8 acres in size and make them level, certain areas of our site were cut up to 8 inches into the subsoil clay. It is a long road back to amend this kind of cut into fertile soil. We made our initial rice fields in 2012 and as of this writing the cut side is still much less productive than the fill side. Likely they will continue to need more compost and manure than the fill side for years to come.

Small rice systems can be created using only spades. I dug a nursery paddy system one year totalling about 1/20th of an acre in area, starting in quite uneven ground. It took me about one solid week of work. The leveling process is very intuitive. I built the berm first and introduced some water into the paddy until half of the area was flooded. Using a shovel, I moved the dirt above the water into the water, using the shovel to precisely cut the surface to the level dictated by the water, and filling the low side very precisely to bring the bottom up to the water level.

But these paddies were each quite small, only about 25 to 30 feet on a side. As scale increases, the quantity of material to be moved also increases exponentially, and so the greater the argument for heavy equipment. Very large scale projects argue for bulldozers and graders as well as an excavator and a ground support crew. Each site is different as are the requirements of different growers and the role of the rice system in their larger land-use strategy. Unfortunately, mistakes in design have a tendency to be expensive and long lasting due to the high cost of earthmoving. It is worth doing as much research up front to develop your site plan and equally worth hiring operators who are skilled at doing precise, unusually demanding heavy equipment work.

Moving stored water can be relatively easy using gas-powered semi-trash pumps. These can deliver large volumes of water in a few hours so long as the distance and lift are limited. Over the years we have added a pipeline system with valves to use with our pumps instead of the flexible hoses that must be dragged from one fill location to another. We are also working on bringing our vertical axis windmill to bear, and then will be able to use both wind power and gas power as a backup, using the same water distribution infrastructure.

Because individual growers in the Northeast do not have the opportunity to band together as a village or district full of rice farmers can do in countries where rice is commonly grown, our paddy and water systems will tend to be quirky one-offs for some time to come. Hopefully eventually enough fellow growers can come together to create some of the elegant economies of scale such as can be witnessed in Japan and elsewhere in Asia.

Above: a berm and irrigation channel in Bibai, Hokkaido, Japan.

Spring Tillage

Rice fields are prepared in the spring just prior to planting. The usual method for preparing paddy fields is referred to as “puddling.” Water is introduced into the field and tillage implements mix the water and soil to achieve thick but flowable consistency. This incorporates any trash or stubble from the previous year and helps level the paddy. A very level planting surface is crucial for a good crop outcome, so thorough attention to puddling is imperative.

To begin, I close all field drainage outlets and begin to flood. I flood until the entire field is awash with water, with maybe just 10% of the land, the highest areas, above water. I rototill the field with a rototiller on a 3-point hitch attached to a 34 hp four-wheel drive tractor. The tractor tends not to get stuck despite being in a huge mud puddle because it is essentially swimming along on a level plane and does not have to pull its weight out of a hole. We also added detachable “cage wheels” to this arrangement last year, which enhanced the performance of the rototiller by making the tractor ride more evenly on the paddy floor.

Puddling is a very counter-intuitive approach to field preparation that will strike many Northeastern farmers as strange or wrong. However it is the standard way to prepare rice fields. The principle is the same, whether the puddling implement is a shovel, a water buffalo, or a tractor and rototiller.

I find it usually takes at least two passes to get a field properly prepared. The first pass mixes the soil with the newly-introduced water. I make several extra passes over the 10% of the ground that stands above the water level, until that matter is dispersed into adjacent lower ground.

A few days after the first pass I usually find that the clods of soil have softened quite a lot. Puddling a second time produces a smoother result, and ideally the soil-water mixture now forms an even thick fluid about 4-6 inches deep. The paddy soil mixture should be thick enough that you can make a groove in the surface with a tool that will remain visible, but thin enough to be able to flow somewhat.

After the second puddling, I allow the soil to settle out of the water. When the water is clear, I drain excess water off the surface until 50% of the land is exposed. One should never allow muddy or cloudy water to drain out of a paddy if at all possible. Then I assess the depth of the deepest puddles of standing water in the field. If the depth exceeds one inch, a third pass may be called for. Water may need to be re-added to help facilitate leveling, and drained off the surface once it has cleared.

Summer

Transplanting - June

The paddy field final tillage needs to be done at the time the seedlings are ready to be transplanted. There is usually a reasonable window for seedling readiness, so that field work can aim for this target. As soon as the field is ready and has settled for 24-48 hours, the transplanting can proceed.

For machine transplanting, excess water should be drained out of the field. Excess water in the field can make it harder for the machine to embed the plants properly and will result in the machine throwing a small wave as it works, which can smother or uproot already completed work. For hand transplanting, water level is less critical.

Machine transplanting involves the use of a transplanter. While transplanters are very common in modernized Asian farming systems they are all but unheard of in North American rice agriculture. They are fairly easy and inexpensive to import as used items, and cost from about $1500-$3000 including all shipping costs. They are usually ride-on, gasoline powered machines, and can move on land or in a paddy environment. There are several different styles and vintages of transplanter available, from small, walk-behind devices that plant two rows (including ones with a hand lever rather than a motor) all the way to machines that plant eight rows or more. The most common seem to be four, five and six row machines. In this range, the implement is small enough to do small and irregularly shaped fields but large enough to transplant up to an acre or so per day.

About half of the work of machine transplanting is actual driving and operating of the implement, and about half is carrying mats to the machine and loading it. The trays of rice seedlings are transported to the edge of the field being transplanted (for which handy racks or carriers can be made or bought) and can be rolled up like a jelly roll. The operator picks up a mat roll and unrolls it into the seedling magazine of the transplanter. Most transplanters can hold two mats per row, and have some space to stow additional mats. We have found that this capacity is usually enough to work down and back even our longest fields, so that we return to the source of seedlings the majority of the time, minimizing reloading effort.

Hand transplanting requires no special equipment but is a lot of work. Some rice farmers are able to plant about 1/10th of an acre per day, which would be 4200 plants at a minimal density, but I seldom am half that productive. Usually when hand transplanting I try to approximate a 1’ x 1’ grid, but it is also possible to use strings and lines to get straight rows. If you are planning on cultivating between rows, this may be critical.

The following chart shows the significance of the choice of transplant method. For operations of an acre and larger, hand transplanting represents a major labor commitment. With machine transplanting this is much less the case, and an investment in a transplanter will redeem itself in four years while also being more economical than even an ace hand transplanter. However, investment in a machine transplanter is at its most economical when multiple acres are transplanted.

Given the high cost of hand labor and the scarcity of workers with the skill and stamina required to plant 1/20th of an acre per day (let alone the “ace” rate of 1/10th of an acre per day!), machine transplanters seem like a very sensible investment even for farms with as little as half an acre in cultivation.

Method	Hours of labor per day	Acres planted per day	Total labor hours per acre	Cost Per Acre at $12 / hr labor	Annual Machinery Ownership Cost (4 yr payback)	Total cost/ Acre	Each additiona l acre
Hand Transplant, ace transplanter	8	0.1	80	$960	$0	$960	$960
Hand Transplant, average speed	8	0.05	160	$1920	$0	$1920	$1920
4-row transplanting machine, crew of 2	16	0.75	21.3	$256	$500	$756	$256
6-row transplanting machine, crew of two	16	1	16	$192	$700	$892	$192

Following transplant the young seedlings will take some time to root in their new surroundings. It can take 7 days or so of adjustment before they really begin to take off and grow. In the meantime, add water back in so long as the plants are not submerged.

Machine Transplanting at Boundbrook Farm, 2017

Looking after the Crop

As rice plants grow, water levels can be increased, ultimately to a level of four or five inches. If leveling has been done well, and transplants are large and healthy, and water is kept as high as possible throughout the early period, there is a good chance that weeds can be adequately suppressed. Beware any high-lying areas or islands, as these will certainly yield a profuse crop of weeds unless addressed.

Bear in mind that water levels are as much of a weed control strategy as they are a method of irrigation. Rice can be grown in very shallow water, or in soil that is merely very damp and be quite happy. However without adequate water depth, no weed control benefit is obtained and the slow-growing rice crop can be overwhelmed.

We use the "aigamo" or "duck rice" method of farming which entails introducing small ducklings into the paddy approximately 7-10 days after transplanting. This method is well-documented in The Power of Duck[9], in English. It is a method with a certain amount of nuance to it, requiring that flock health, water depth, plant development, security from predators and weed suppression all be carefully monitored and balanced. We have had both successes and frustrations with this method but still believe it is probably the best non-chemical weed control approach. Therefore, duck rice systems dominate the middle part of the season here at our operation.

Farms that opt for other weed control strategies will probably spend more time using mechanical controls in the rice fields. With the aigamo method, when things are working as they should, people usually do not need to enter the rice paddy.

Without a weed control strategy, several weed species will present themselves, including spikerush, barnyard grass, and pickerel weed.

Pickerel Weed, *pontederia cordata*

[9] *The Power of Duck,* Takao Furuno, 2001, Tagari Publications, Sisters Creek, Tasmania, Australia

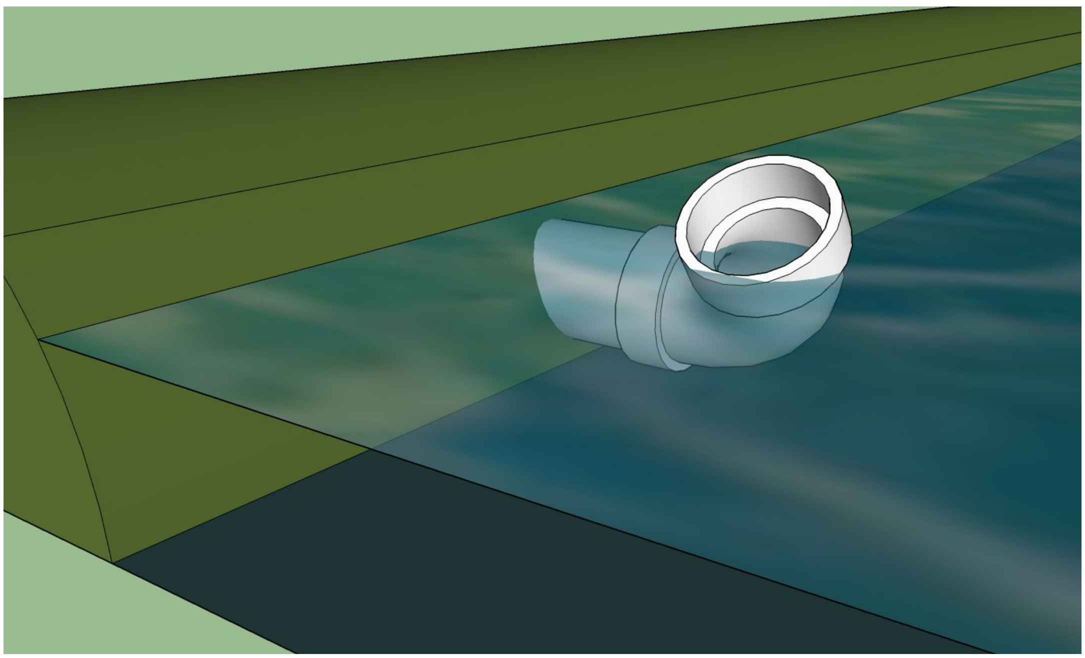
Barnyard Grass, *Echinochloa*

Spikerush (*Eleocharis*)

Of these three weed species that are the chief culprits in our Champlain Valley operation, barnyard grass is particularly vexing because it closely resembles rice plants. Growers will need to learn to differentiate rice plants by their auricles at the leaf nodes, or by the fact that barnyard grass has a reddish stem and more dull green leaf than rice. But when plants are very young and small, these differences are less pronounced.

Particular consideration to weed control can be found in part three, where our weed control trials will be discussed in detail.

Apart from weed management, the rice farmer also needs to regulate water levels as needed. For us this usually consists of a walk to check levels in each field once each morning, and then starting the pumps to fill one or more paddies as necessary. Also, following a rain, paddies should be checked to be sure they are not too full. Rotating ell outlets through paddy walls are a good way to regulate maximum level in many cases.



Above: A length of 4" pvc pipe and a 90 degree elbow buried in the berm wall can be used to set water levels. The elbow is friction-fit onto the length of pipe and can be rotated to precisely set the maximum level.

Late Summer

By early August, most rice varieties will be flowering and moving into the ripening phase. Around the 7th of August, I remove my ducks from the field and shortly afterward I begin facilitating drainage.

While the farmer can't do much to prevent late summer and early fall rain from entering the paddy, he or she can ensure that standing water will flow out as quickly as possible. There is considerable time for the paddies to dry out before harvest. If the process of draining and drying is begun early and uniformly throughout the field, and rainfall is not too heavy, with luck your fields may be dry and firm when time comes to harvest.

In Japan, farmers prefer dry fields but wet weather or typhoons can spoil efforts to dry things out right through harvest time. It is wise to have a harvest strategy that will get the crop even if the fields are mucky or soft at the time the harvest needs to happen.

For hand harvest, wet conditions are annoying but won't prevent the work from happening. For machine harvest, they can result in machines sinking in and getting stuck, which is no fun.

Other than helping things dry out, there is not very much that the rice farmer can do in August or early September.

Harvest Time - September and October

By mid September or early October, the rice should be ripening well. I check the plants for ripeness by peeling a single seed and crunching it between my teeth. At a minimum it should have a little crunch to it. Some varieties are more prone to loss from shattering than others. The main Japanese varieties that I have grown seem to be quite resistant to it, so this means that there is usually very little at risk in waiting for the rice to fully ripen in the field. Fully ripened rice is hard between the teeth and can be crunched only with a bit of effort.

Generally, combine harvested rice should be harvested at moisture contents in the low 20% range. Such rice will need to be promptly dried down to 14% moisture or less. Very high moisture content rice (in the high 20% range or higher) will require a lot of unnecessary effort and / or fuel to dry and may also develop seed fractures during the process of drying, which can result in a lot of loss during hulling and polishing.

We prepare for harvest by getting a chain of devices ready, including the dryer, the gravity wagon, and the combine. When things are running smoothly we can harvest several acres per day, but careful planning is needed to ensure that there is capacity for the harvested grain to move through all the steps in order to be able to be stored safely.

As we have developed our operation we've changed our equipment approach to harvest and postharvest processing quite a lot. In general we've moved from hand sickles and an antique thresher, and a very basic hulling machine to a suite of mid-sized equipment typical of a small rice farm in Japan. As with transplanting, identifying ways to bring in used small farming rice equipment from Japan changed our entire operation.

The first link in the chain is the rice combine. The rice combine has a different type of head than other small grain combines, and is designed to go through rows and efficiently pick up rice, even if it is somewhat lodged. Additionally, our newly-acquired model has tracks, which greatly reduce the risk of getting stuck if the field is wet or soft.

The second link is the transport gravity wagon. This too is imported, and is designed to ride in on a flatbed truck. It features an electric auger for discharging contents into a rice bin or dryer.

The final link is the dryer. Japanese rice dryers are recirculating batch-type electric and kerosene units that feature fully automatic control. A small rice dryer can dry one ton of rice from 24% moisture content to 14% in about 16 hours.

Step	**Tool Used**	**Cost of Tool**	**Prepares rice for**	**Quantity / Day**	**Pros**	**Cons**
Reaping	Sickle	$5	Air drying in sheaf or threshing	0.25 ac	Cheap	Laborious
Reaping	Gas Walk-behind reaper-binder	$1000, import	Air drying in sheaf or threshing	1 ac/day	Allows for air drying	More steps than combine process
Combine Harvesting	US type small grain combine	$3000-10000	Dryer	>1 ac day	Not imported	Machines with tires prone to get stuck
Combine Harvesting	Japanese Tracked type	$5000-10000, import	Dryer	>1 ac day	Easy to operate, reliable, efficient	Imported item, foreign language documentation
Drying	Air Drying Rack for Bound Sheaves	$100	Thresher	n/a	Cheap, no fuel required	Slow, works poorly in cold wet conditions, laborious
Drying	Conventional US drying bin	$12500	Huller or storage	5-10 tons	Large capacity, readily available	Expensive to buy and run

Drying	Homemade wood fired batch dryer	$1000	Huller or storage	1 ton	Cheap to build and run	Somewhat laborious and difficult to use well
Drying	Japanese Recirc. Batch Dryer	$3000-5000 import	Huller or storage	1 ton	Excellent automated drying	Imported item, foreign language documentation
Threshing	Manual Threshing	none	Huller or Storage, depend. Dep on moisture %	500 lbs/day?	No tools needed, straw can be saved easily	Very laborious
Threshing	Stationary Thresher	$500-2000 Maybe import	Huller or Storage, Dep on moisture %	1 ton per day or more	Faster than hand threshing, straw can be saved easily	Somewhat laborious

There are several methodologies that can be used toward a successful harvest. The right one for any operator will have a good balance between the area undertaken, the supply of labor, and the ability to invest in good tools.

For our operation, we began with more of a hand-labor bent but have moved over time towards a more machinery-intensive operation along the lines of a small Japanese rice farm. Part of what encouraged us to become more mechanized was the realization that used rice farming equipment can be readily and cheaply imported, giving us affordable access to well-made tools that are otherwise unavailable in the U.S. machinery market. Ultimately, the labor savings that come from mastering these devices have, for us, outweighed the considerable learning curve of usage and maintenance, and other costs of ownership.

Often, Japanese farmers will have kerosene-fired dryers on their own farms to dry down their crop. These dryers have fans and can regulate drying cycles by sensing the quantity of rice that they contain and the starting moisture content and temperature. They run through cycles of heating, mixing, and blowing the column of grain until the desired final moisture is obtained, at which point they shut off.

Japanese practice is to dry to the 13.5-14% moisture content range in preparation for hulling. This is low enough to ensure that mold cannot set in given normal storage conditions, but not so low as to damage flavor or needlessly consume fuel or to reduce the sellable weight of the crop unnecessarily. Arkansas Cooperative extension calls for drying to 12%. Part of the difference in standard may be explained by the dispersed nature of the rice marketing and distribution system in Japan, as rice is stored and swiftly delivered to market relatively close to the area where it was grown, through a network of relatively small-scale processing hubs, commonly run by the JA (Japan Agriculture) network of coops.

Milling and Distribution

The final step in bringing the rice crop to market is to mill it into a form that the consumer can cook. Almost universally in the US rice industry, and often in Japan too, farmers only produce grain and may deliver it straight from the combine to a local elevator to be dried and subsequently processed. This practice is impossible in the Northeast, as no such processing hubs or elevators exist. So, instead, let's consider the farm-processing examples provided by Japan.

Farms that have their own dryers may have their own hulling and bagging arrangements as well. Most Japanese hullers are box-shaped devices about four feet long, three feet wide and three feet high. The hulling action is performed by passing rice through a narrow gap between two rubber rollers, which turn at different speeds. The resulting slippage and friction rolls the rice grains and abrades the husk off of the the grain of rice, without being so harsh as to abrade the bran of the grain of rice itself.

Next, the mixture of grains and husks is passed through a blower chamber that carries away the husks and any small particulates. The grain falls into a collection area and is lifted by a conveyor to the separator table.

The separator table is a critical aspect of the Japanese hullers. The rice is spilled onto seven sloped sheets of metal that is textured in a kind of dimpled pattern. The array of seven trays shakes back and forth rapidly, causing the successfully hulled rice to be cast towards the left side of the tray while rice containing unhulled seeds with stay close to the right edge. This imperfectly hulled product is diverted back to the original hulling rollers for a second pass. Having a functional separator to remove unhulled seeds reliably and efficiently is critical to being able to produce a marketable brown rice product.

The output of the huller should then contain no hulls whatsoever, but it may contain some cracked or undersized rice pieces. Usually, a second smaller machine, a sifting and bagging unit, receives the output of the huller. This unit has a rotating sieve that screens out these smaller pieces and passes only whole grains of rice into a reservoir. These machines also feature programmable scales that receive the output from the reservoir, but shut off when the target weight is reached. Using the huller and the sifter and bagger simultaneously, the farmer can produce a steady output of standard 30kg bags.

These bags can then be tied up and placed in a rodent-proofed storage area. Storage conditions should be regulated to have cool, dry conditions, ideally below 55 degrees F and below 50% humidity. Our storage area is insulated, and has an air conditioner and a dehumidifier to regulate the interior conditions when necessary. Normally, once winter sets in (and the rice building is unheated) these devices are no longer necessary.

In Japan, farmers rarely store large quantities of rice as hulled paddy rice. I believe this is because the crop takes up less space as brown rice, and because all the messy hulling process is best dealt with at once in the fall rather than in installments throughout the year. It's worth noting though that iin most cases in Japan, brown rice is an intermediate product, not a final one. While it could be eaten as brown rice, it is usually not. And generally, it is not the farmer but either the retailer or the customer who performs the final processing step of polishing it prior to cooking. Freshly polished rice is highly valued in the Japanese food marketplace.

For our farm, in addition the huller we also have a polisher to make our brown rice into white. The polisher accomplishes this by using a steel shaft with burrs along its side to roll the rice against a perforated steel screen, abrading off the bran layer. A vacuum surrounds the outside of the screen, sucking particles of bran away. The degree of polishing is controlled by a spring loaded dial that sets the force required to move the outlet plate. A fully tightened dial will result in more aggressive polishing with the rice under considerable pressure within the polishing chamber. A lighter setting is more gentle, which seems better for grains that are more delicate. But generally I have had few problems polishing with two passes on the maximum settings.

Brown rice from the huller (left) and white rice from the polisher (right)

Without at least a huller it is hard to see how any rice grower could enjoy much of their crop and get it to market. Besides hulling, every other step in the growing process has a machine-free option that could be at least somewhat viable, but hulling rice traditionally involves truly primitive and onerous work, thumping the rice in a kind of large mortar and pestle, and then winnowing it.

In rice growing cultures, this consumed huge quantities of mostly women's labor. I can't imagine approaching rice growing in our current cultural context.

Other Northeastern growers have approached the challenge of hulling differently, seeking out antique or imported hand-powered devices or devising prototypes to do the job. I certainly can't speak to the effectiveness of devices I've never had a chance to try, but for sheer speed and perfection of the final brown rice product, I believe the Japanese rubber roller hullers with their integrated gravity tables are hard to beat.

Wet Rice Organic Weed Control Trials

In the 2009 Rice Growing Manual, Takeshi Akaogi reported that weed pressure hadn't presented much of a problem to growing without herbicides. Our experience was different, and by 2014 we had identified weed pressure as a chief culprit limiting the productivity of our operation.

Since transplanted rice grows in a shallow, flooded environment, and since it is initially covering the growing area rather sparsely and grows slowly, there is ample opportunity for aquatic weeds to emerge if conditions are right. In our case, our project was large, and the flaws in the paddies, including deep spots, high spots, and leaks in the dikes, were many. These all exacerbated weed growth and the scale of the problem meant we were constantly behind in controlling weeds.

Of course, with a soft mucky environment that is nearly impossible to walk around in, pulling weeds is quite a bit more difficult than on land. Furthermore, uprooted weeds often can't be ejected from the growing area, and must be turned upside down or plunged into the mud. Many weeds survive this treatment.

For 2012 onward, we looked to the method outlined in Takao Furuno's The Power of Duck, which described a similar experience of the author initially struggling with weed pressure and low yield, and which presents a management solution by managing ducks in the rice paddy according to a certain method. This book is extremely well written and the English translation is excellent. However often I found myself poring over the text like a scholar of some ancient document to guess what the author assumed I already knew, or for solutions for problems I was having that the text didn't seem to address.

Part of the limitation of the usefulness for Northeastern Farmers is that the rhetorical style of books like this is quite a bit different in Japan. And of course, the units are all different, mostly being metric but also including some traditional Japanese measurements. But the biggest problem is that Takao Furuno really wrote the book for veteran rice farmers and so assumed some baseline understanding that I really did not have.

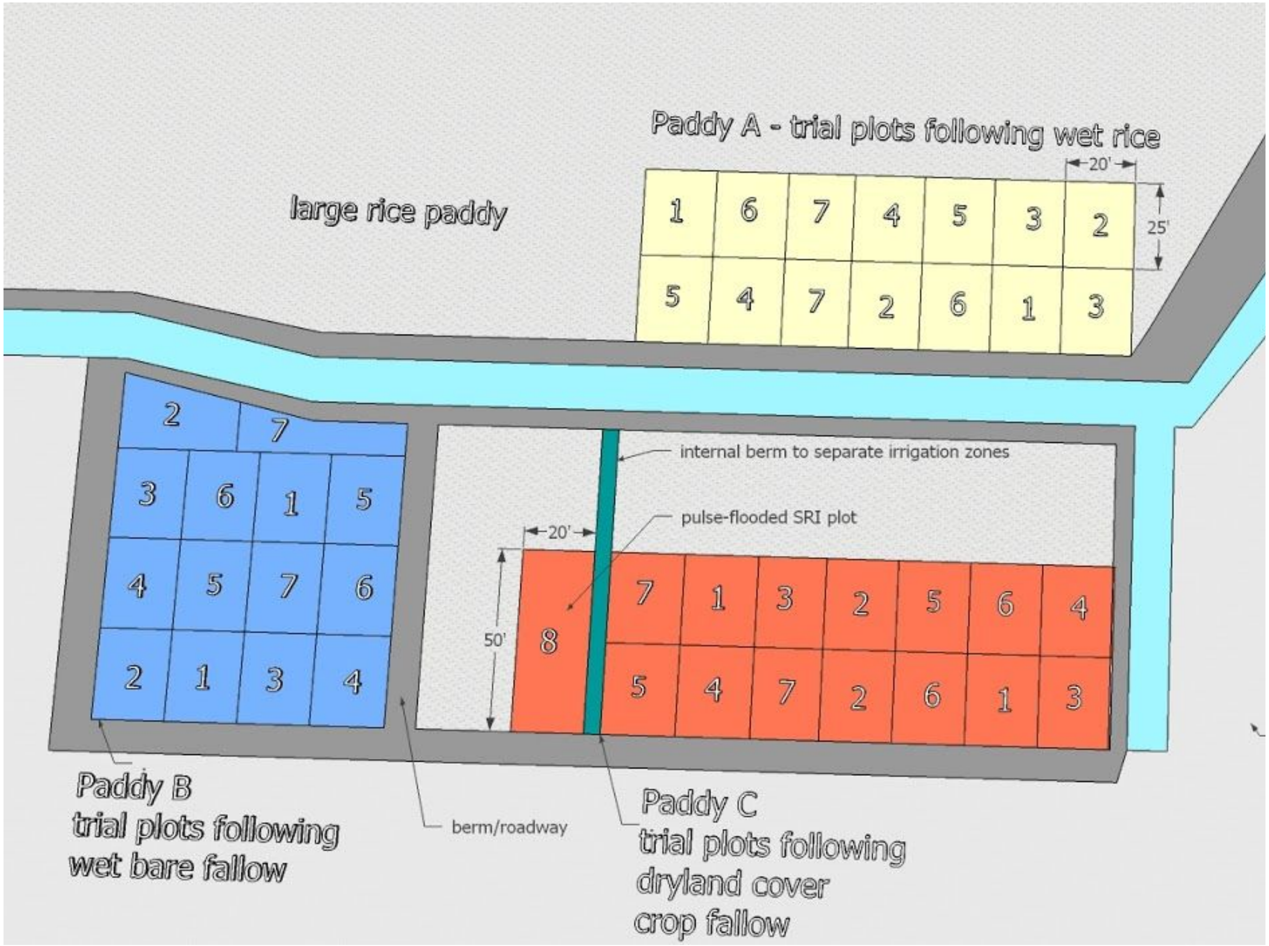
For this reason I embarked on an on-farm evaluation of weeding methods with support from Northeast SARE to compare the duck weeding method with some alternatives. Our trials took place in 2016. Chiefly I set out to gauge inputs versus output across several methods, including duck-rice and the use of azolla.

Concurrent with this I continued to pursue a better understanding of the Japanese way or rice farming generally and the duck-rice method outlined by Mr. Furuno specifically. To this end I went to Japan and visited several organic operations and participated in the Japan Duck Rice Farmer's conference in July, 2015. I have kept up a correspondence with Takao Furuno and have been able to get some key questions addressed, as well as to develop a better global understanding of how the Japanese varieties that I grow in Vermont are normally grown in their native country.

Experiment Design

Initially, the methods I had intended to compare were as follows:

1. Control - Flooded but not weeded
2. Flooded and hand weeded
3. Flooded and containing azolla but not weeded
4. Flooded and containing azolla and hand weeded
5. Flooded, with ducks, but not weeded
6. Flooded with ducks and azolla and not weeded
7. Flooded, with ducks and azolla and hand weeded
8. Pulse-irrigated SRI method



Additionally, we set out to cross compare these against three different modes of prior year usage, in order to assess whether wet fallowing, dry fallowing and cover cropping, or rice cultivation made much of a difference in weed pressure. During the 2016 growing season we attempted to establish these three different prior year use patterns, but nature began to interfere with the experiment design even at this early stage.

Revisions to Design

The Paddy C area was intended to have a prior year usage of a dryland cover crop. This might have worked in a normal year but rainfall was so heavy in June and July that the field could not be worked. We did manage to plant one cover crop of winter rye late in the season but it performed poorly.

The second development that led us to change the design was the mercurial nature of our azolla species. Azolla is a floating fern that behaves a little like duckweed, but is a nitrogen fixer. As such it has great potential to add fertility to rice systems. However we found it hard to predict how it would grow. It seemed to grow very rapidly in certain situations and shut down in others. Cool temperatures (below 65 degrees) resulted in almost no growth, but hot temperatures with lots of sun seemed to also result in the leaves turning red and growth shutting down. I have since learned that Azolla is very sensitive to phosphorus shortages in the water, and that may have had something to do with it.

Also, I had been growing a species of *azolla caroliniana*. I have since learned that this species is one of the more difficult to manage. In the future I hope to try out azolla filiculoides, which is native to the Pacific Northwest. All azolla species are 100% winter killed in a climate like vermont so the risk of introducing them to the local ecology is nil.

Interestingly, during my visit to the Japanese Duck Rice conference, I saw no azolla either at Takao Furuno's farm or at other participating farms. I did ask about it and several farmers had tried it but found it too difficult to manage. The general sense I got was that azolla has potential but adds too much complexity, and the general duck-rice system works adequately well for growers yet remains within their management capability.

Due to troubles managing it at home and the lack of interest in it I witnessed in Japan, I made the decision to eliminate the azolla variable from the trials, this greatly simplifying the experiment. I set out to compare hand weeding alone, ducks alone, and ducks and hand weeding against each other.

Each plot was 25' x 30', or 750 square feet, 0.017 acres. We compared management methods from the time of transplant (June 20th) to the time of full canopy formation (August 7th), assessing resulting yield, which was separately harvested and weighed, and labor inputs into the project during the trial period.

The pulse-flooded trial was also eliminated from the experiment due to difficulty managing the separate water levels enough to permit foot traffic for the kind of weed management SRI proposes. I decided that a serious evaluation of SRI was beyond the scope of what I could manage within this experiment.

Evaluating Results

Since I was chiefly interested in managing labor and increasing yield, I divided pounds of plot yield by hours of labor to yield a factor that represents the labor efficiency of the competing methods, and applied a qualitative description of the degree of weed suppression.

FNE 15-813 Field Trial Results		Control	Hand Weeding	Ducks Only	Ducks and Hand Weeding
Following Rice and Ducks	Yield, lbs	2.00	28.10	31.00	36.00
	Labor	0.00	14.25	0.00	5.00
	Lbs yield / labor	n/a	1.97	n/a	7.20
	Weed Suppression	Very Poor	Good	Very Good	Very Good
Following Wet Fallow	Yield, lbs	5.00	15.50	29.20	34.00
	Labor	0.00	13.30	0.00	5.50
	Lbs yield / labor	n/a	1.17	n/a	6.18
	Weed Suppression	Very Poor	Good	Very Good	Very Good
Following Cover Crop	Yield, lbs	2.90	18.50	26.00	29.80
	Labor	0.00	12.50	0.00	8.80
	Lbs yield / labor	n/a	1.48	n/a	3.39
	Weed Suppression	Very Poor	Good	Very Good	Very Good

The control plots yielded very poorly with the rice plants largely choked out by barnyard grass. Hand weeding plots out-yielded the control plots at the cost of copious amounts of hand labor to keep them clear. But yields in the duck rice plots topped the hand-weeded plots, presumably due to the constant agitation of the water and the presence of duck manure.

The pounds of yield gained per hour of labor is an important number, because depending on how highly the farmer values their time, it simply may not make economic sense. In all the hand-weeding only trials, the amount of production gained by hand weeding is between one and two pounds of rough rice gained per hour of work. Especially when one considers additional work and loss of crop weight in harvest and processing, it is hard to imagine this labor investment paying off. Perhaps in a traditional village agriculture system it might be worthwhile, from a survival standpoint, for a person to pull weeds all day to increase the production by fifteen or twenty pounds because that is still a considerable energy gain, considering the person would only eat one of those pounds during the day it took to do the work. But from a dollars and cents standpoint, the calculation is simply brutal--the rice grown simply cannot pay an hourly wage unless the crop is priced exorbitantly.

Duck plots where supplementary weeding took place (far right) were the best yielders in the trial, and consumed fewer hours of labor than plots with hand weeding alone. An hour spent weeding in the duck plots resulted in greater gains of production than in the hand labor only plots. However duck plots without hand labor were also respectable.

Further Thoughts on Weed Control

During the trial, additional ideas came forward about how to weed more efficiently either alongside ducks or in the absence of ducks. Several ideas have come forward. The first is the use of small motorized or nonmotorized walking cultivators. I devised one out of a Mantis rototiller by fabricating a small boat to it, that was narrow enough to thread between the rice rows. It worked great, so long as the weeds were small and the mud fairly loose and well flooded. It would ball up with large weeds.

A further improvement on this concept is the use of a string trimmer with a boat arrangement as an inter-row weeder. I have recently discovered this made-in-Japan attachment to a straight shaft trimmer but have not had a chance to try it yet. It has a blade that attaches to the trimmer shaft that whips through water and mud. It seems that this would offer all the advantages of my homemade Mantis arrangement while also being lighter and performing even better.

Looking at the entire rice season, weed control is clearly one of the main concerns for growers. If you can get a solid method that delivers good production for effort invested, you are well on your way to setting up a successful operation. I had inclination towards the duck method prior to embarking on the trial and the results have confirmed this.

I would highly encourage any prospective Northeastern rice farmer to acquire a copy of The Power of Duck directly from the publisher. But here are some of the key highlights of the duck method:

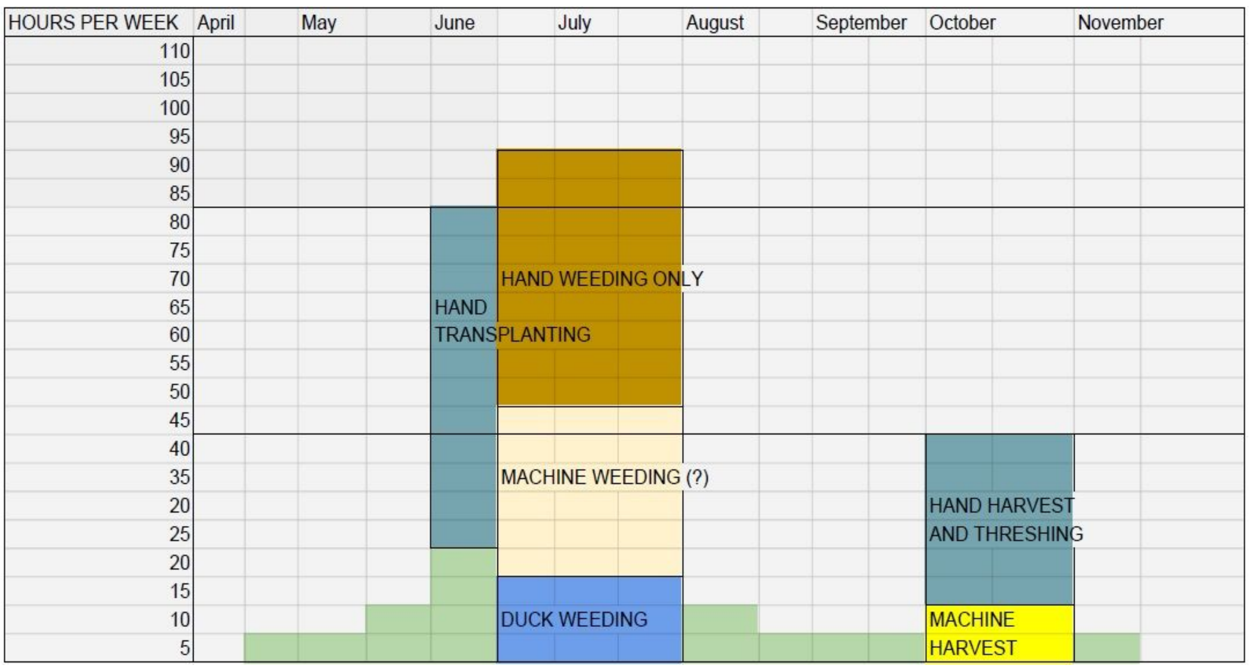
1. About 100 ducklings per acre, but subdivided down to plots no larger than 50 ducklings to 0.5 acres.
2. Ducklings should be hatched around the same day as transplanting is done in order that they be around 10 days old when introduced to the rooted, transplanted field
3. Survival of the ducklings depends on them being able to fluff and dry themselves as needed. Each fenced zone should have an easy ramp out of the paddy and some shelter. Feed the ducklings daily here to encourage them to come there
4. Constant vigilance is needed to discourage predators. Trap, hunt, fence them out, whatever it takes
5. Water level should be rather low when ducklings are first introduced, and may need to be decreased if there is a very hot spell, but can usually be increased up to 4”-5” after a few weeks and stabilized there. In general, the deeper the water, the better weed control, but not so deep as to drown your plants
6. Ducks are removed from the paddy when plants begin to ripen (usually early to mid August).

Visiting with Takao Furuno at his farm in Tento, Fukuoka, Japan in July 2015

Conclusion

Our intention as farmers and in writing this report is to progress towards a coherent approach to small-scale rice growing, considering scale-appropriate methods and devices for the key rice-growing chokepoints, notably transplanting, weed control, and harvest. We compiled this visual overview of comparitive methods.

LABOR HOURS PER WEEK PER ACRE



These figures are roughly based on labor inputs that we have tallied here over time. For instance, an acre of crop required about five hours per week through April and May, increasing to maybe ten as the field is prepared for transplanting. But if transplanting is done by hand, labor requirements increase to 80 hours per week in June. However if a machine transplanter is used, per acre labor is only about 20 hours.

Starting in the second half of June, the acre grown using hand labor alone requires 90 hours per week of work. The beige column shows how maybe, with the implementation of good weeding devices, this might be reduced to 45 or so hours per week. But the farmer using ducks for weeding only spends about 15 hours per week per acre during this phase, mostly light labor monitoring how well the ducks are doing their job.

In August, work drops off for all farming approaches as there isn't much to do as the crop ripens.

Starting in October another labor issue emerges as the farmer using hand methods has to put in a lot more hours than the one who can deploy a combine.

The general picture is that hand-labor only operations may be difficult to make viable, even with their products priced at top dollar. But it is certainly within the realm of the possible. However with the addition of ducks, the annual labor picture of hand labor operations is considerably better. We have also found that with appropriate-scale equipment for transplanting, harvesting and milling we have been able to get work done smoothly enough to be able to contemplate undertaking additional fields.

This is a challenging field of agriculture, adapting a crop that is very well understood elsewhere to our landscape and cultural context, and nobody should expect it to be smooth or free of surprises. It is a good domain for those who enjoy solving puzzles and drawing information from a variety of sources. And, not least of all, quality rice is a rare delight in the U.S. food marketplace. Apart from people who have lived in Asian countries with strong traditions of local growing and milling, most Americans are not accustomed to finding delight in a bowl of rice. It is a special honor for a farmer to be able to open this world of experience to neighbors, and to begin to make a place for this ancient and venerable food in our landscape.

Hand methods at work in Vermont, at Boundbrook Farm, 2012