Perennial Staple Crops of the World

This is a companion piece to "Climate Stability with 'Permanent Agriculture,'" an article that appeared in the Spring 2011 issue of the Permaculture Activist. *That article laid out the potential for perennial farming systems like agroforestry and perennial crops to sequester carbon while providing multiple social and ecological benefits. This article reviews perennial staple crops, a little-known group of species with tremendous potential to address world problems.*

Perennial Staple Crops are basic foodstuffs that grow on perennial plants. These plant sources of protein, carbohydrates, and fats can be harvested non-destructively – that is, harvest does not kill the plant or prevent future harvests. This group of crops includes grains, pulses (dry beans), nuts, dry pods, starchy fruits, oilseeds, high-protein leaves, and some more exotic products like starch-filled trunks, sugary palm saps, and aerial tubers.

These trees, palms, grasses, and other long-lived crops offer the unique possibility of crops grown for basic human food that can simultaneously sequester carbon, stabilize slopes, and build soils as part of no-till perennial agricultural systems. Such production models seem the most likely of all regenerative farming practices to approach the carbon sequestering capacity of natural forest, because they can mimic the structure of a forest most closely.

Perennial staple crop systems are resilient in the face of extreme weather, surviving drought, flooding, and storms better than most annuals. These food forests can be long-lived, no-till, and low-maintenance – which sounds like a rather utopian base of subsistence. They do however have harvesting and processing challenges – for example most peach palm varieties have tall, very spiny trunks that must be climbed for harvest (both dwarf and spineless forms have been selected, but not yet one with both qualities).

Note that these benefits apply particularly to polycultures (multi-species systems) of perennial staple crops. Monocultures (single-species plantations) appear to sequester less carbon, are more fragile in the face of pests and extreme weather events, and certainly provide less additional social and ecological benefits (see "Climate Stability with 'Permanent Agriculture'" in *Permaculture Activist* # 80).

Most of the species profiled here are still under development. Though they may have been grown for millennia, almost none have received the kind of breeding attention that annual staples like corn, rice, and wheat have received. Nonetheless, many actually outyield annual staple crops even in their neglected state. Others, notably perennial grains, are part of active breeding efforts and are showing great promise. Globally, a massive effort to fund breeding work, particularly providing additional resources to individuals and organizations already at work on perennial crops, should be an important component of climate change prevention.

Perennial Crop Candidates by Climate Type

The **lowland humid tropics** are rich in productive starchy perennial staples. Crops like bananas, breadfruit, sago palm, peach palm, air potato, and Tahitian chestnut are very high-yielding. The region is also well-supplied with perennial oilseeds like oil palms, Brazil nuts, and avocados. Perennial proteins are less available, with the few ready for prime time including breadnut and some other tropical nuts.

For **arid and semi-arid tropical zones**, the situation is also fairly promising. Carbohydrate crops include date palms and mesquite pods. Perennial protein crops include: perennial lima beans; buffalo gourd seeds; moringa, baobab, and chaya leaves; and extremely drought-tolerant edible-seeded acacias.

In the **highland tropics**, several unique crops offer great promise. Carbohydrate crops include lucuma fruit, mesquite pods, and the starchy trunks of enset. The remarkable chachafruto tree is a perennial bean with phenomenal production. Several other perennial beans including runner beans are suited to the highland tropics.

Mediterranean climates can feature carbohydrate crops like carob, dates, and chestnuts. Protein sources include avocado, almond, and pistachio. The olive is of course among the world's finest oil crops. This is also the only region with an oak (*Quercus ilex*) that is functioning as a proper crop.

Cold temperate climates are in an interesting situation. We have the least number of staples ready for prime time, but by far the most breeding work being done. Chestnut and hazel are perhaps the best carbohydrate and protein crops (respectively) we have at present, with pecan our best oilseed. Edible leaf mulberry is also a fascinating and productive candidate. However, perennial grain development is moving ahead rapidly and the outlook for cold climates looks excellent. These grains may someday join mesquite in **cold arid regions** as the basis of human sustenance.

Barriers to Adoption of Perennial Staple Crops

Why are these crops not better known and more widely grown? Our global food system focuses primarily on annual grains, beans, oilseeds and tubers. These crops provide a yield quickly. Converting to perennial staple crops means facing many challenges.

For one, these crops are difficult to get your hands on. In any given region, few are available. Access to improved varieties is even harder to come by. A network of nurseries is an essential component of getting this plant material in the right hands. This will include navigating lots of permits and paperwork in bringing seeds and cuttings across national lines.

For any individual farmer, getting over the hump of establishment time is a major barrier. Waiting 3-5 years after planting for food or income is difficult for farmers everywhere, particularly where farmers must subsist on what they grow. Climate change funds could and should be targeted on a massive scale to make it possible for farmers to get these crops established. Lack of long-term land tenure is also an obstacle – who wants to plant and care for trees on rented or otherwise insecure land?

Adoption of new crops is also a barrier. People like to eat what they are accustomed to, and won't necessarily eat something new just because it is good for them, grows easily, or helps fight climate change. Fortunately, many perennial staples taste excellent. This obstacle can also be partially overcome by replacing annual livestock feed crops with perennial ones. Hogs and cattle are a lot less picky about their foods than people!

Perennial staple crops, like corn and wheat, often require specialized equipment or infrastructure for harvesting, processing, and storage. This can be low- or high-tech. To implement a mass conversion to perennial staple crops will require development and distribution of the necessary equipment to make utilization possible.

Much research is also called for. Even in cases where selection and breeding work is relatively complete, which species and varieties are suited to a given region? What agronomic practices work best? How can perennial staples be integrated with nitrogen fixing species, livestock, and annual crops? This kind of research should be funded and prioritized as part of global and regional carbon sequestration efforts.

Perennial vs. Annual Crop Yields Compared

The yield figures used to compile these tables do not give a terribly accurate comparison, for several reasons: a) some are measured in fresh weight while others are dry weight, b) some, mostly the annual comparison crops, are fertilized and cared for while others are virtually unmanaged and could have substantially higher yields, c) the crops are grown in different climates with humid tropical species dominating the charts, d) some of these crops are fully domesticated, others virtually not at all, and many are in between, e) some yields include nutshells or inedible pits, and f) yield data on a few of the perennials is extrapolated from smaller land units. Some of these variables favor annuals and others favor perennials, but these tables at least give us somewhere to work from. Yields are in tons per hectare. One ton per hectare is equivalent to 892 pounds per acre.

A brief review of the tables will show that clearly many perennial staple crops are powerful food producers. Particularly in the tropics where candidates abound, these species should be central to carbon sequestration efforts.

Perennial carbohydrate crop yields

Perennial carbohydrates come in the forms of starchy fruits, seeds, nuts, dry pods, aerial tubers, dried fruits, and starchy trunks. These species are ranked by productivity and compared with annual crops. Annual crops for comparison are marked with an asterisk (note that cassava is really a perennial grown as an annual over a 1-2 year period).

Latin Name	Common Name	Climate	Yield t/ha	Product
**Manihot esculenta*	cassava, yuca	tropical	10-90	tubers
Musa acuminata	banana	lowland to highland tropics	3-60	fruit
Musa paradisica	plantain	lowland to highland tropics	8-50	fruit
Bactris gasipaes	peach palm	humid tropics	20-30	fruit
**Solanum tuberosum*	potato	humid worldwide	20-30	tubers
Artocarpus altilis	breadfruit	humid tropics	16-30	fruit
**Colocasia esculenta*	taro	humid tropics	5-30	tubers
Inocarpus fagifer	Tahitian chestnut	humid tropics	4-30	nuts
Metroxylon sagu	sago palm	humid tropics	15-25	dry starch
Dioscorea bulbifera	air potato	humid tropics to highlands	1-19	tubers
Phoenix dactylifera	date palm	arid tropics	11-17	fruit
Pouteria lucuma	lucuma	highland tropics	14-16	fruit
Gleditsia triacanthos	honey locust	temperate	3-15	pods
Artocarpus heterophylla	jakfruit	subtropics	6-12	fruit
Ceratonia siliqua	carob	Mediterranean	2-12	pods
Prosopis spp.	tropical mesquites	arid tropics	10	pods
Treculia africana	African breadnut	humid tropics	5-10	nuts
**Zea mays*	corn, maize	worldwide	4-10	grain
**Oryza sativa*	rice	humid worldwide	3-9	grain
**Triticum aestivum*	wheat	cold temperate, Mediterranean	3-9	grain
Brosimum alicastrum	Mayan breadnut	humid tropics	7-8	nuts
Ensete ventricosum	enset	highland tropics	5	dry starch
Castanea spp.	chestnut	cold temperate and Mediterranean	3-5	nuts
Prosopis spp.	cold-tolerant mesquites	cold arid	2-4	pods
**Sorghum bicolor*	sorghum	arid worldwide	3	grain
Quercus ilex	ilex oak	Mediterranean	1-2	acorns

Perennial protein crop yields

Perennial protein is somewhat rare, particularly in colder climates, and often comes in the form of nuts, which are not ideal because of the frequency of food allergies. Perennial beans are wonderful, and some areas of the world have good ones, though most of us have only limited perennial beans options in serious need of breeding work. Annual protein crops are provided for comparison and are marked with an asterisk.

High-protein perennial nuts and beans

Latin Name	Common Name	Climate	Yield t/ha	Product
Erythrina edulis	chachafruto	highland tropics	13	beans
Artocarpus camansii	breadnut	humid tropics	11	nuts
Phaseolus coccineus	runner bean	tropical highlands	3-5	beans

Phaseolus lunatus	lima bean	tropics	3-5	beans
**Cajanus cajan*	pigeon pea (as annual)	tropics	1-5	beans
**Glycine max*	soybean	cold temperate, tropical	1-5	beans
Juglans regia	walnut	cold temperate, Mediterranean	4.5	nuts
Prunus dulcis	almond	Mediterranean	4	nuts
Corylus spp.	hazel	cold temperate, Mediterranean	2-4	nuts
Cucurbita foetidissima	buffalo gourd	arid cold to tropical	0.5-3.4	seeds
Carya illinoiensis	pecan	cold temperate, subtropics	3	nuts
Pistacea vera	pistachio	Mediterranean	3	nuts
**Arachis hypogaea*	peanut	cold temperate, tropical	1-3	peanuts
Sclerocarya birrea	marula	arid tropics	2	nuts
**Phaseolus vulgaris*	common bean	cold temperate, tropical	1-2	beans
Acacia spp.	edible acacias	arid tropics	1.2	beans

High-protein perennial leaf crops

This chart compares protein yield per hectare, not total crop yields, as comparing leaves to beans and nuts is not very helpful. Annual crops soybean and spinach are provided for comparison and are marked with an asterisk – note that perennial leaf crop protein/hectare is very competitive.

Latin Name	**Common Name**	**Leaf Yield t/ha**	**% Protein**	**Protein Yield t/ha**
Crotolaria longirostrata	Chipilin	5-11 dry	38% dry	2-4.2
Morus alba	Mulberry	16-52 fresh, 8-13 dry	15-27% dry	1.2-3.8
Moringa oleifera	Moringa	10-50 fresh	5.5% fresh	0.5-2.7
**Glycine max*	Soybean	1-5 dry beans	35% dry	0.3-1.8
Cnidoscolus chayamansa	Chaya	20-30 fresh	5.7% fresh	1.1-1.7
**Spinacea oleracea*	Spinach	10-35 fresh	2.5% fresh	0.2-0.9

Edible perennial oilseed yields

In the tropics perennial oil plants already dominate. In colder zones, pecan oil yields 150% of rapeseed, the highest-yielding annual oilseed in the table. Note in particular the high number of palms. Annuals are provided for comparison and are marked with an asterisk.

Latin Name	**Common Name**	**Climate**	**Oil yield t/ha**
Elaeis guineensis	African oil palm	humid tropics	5.0
Acrocomia aculeata	macauba palm	semi-arid tropics	3.7
Caryocar brasiliense	pequi	semi-arid tropics	3.1

Caryodendron orinocense	inche	semi-arid to humid tropics	3.0
Mauritia flexuosa	buriti palm	humid tropics	2.7
Cocos nucifera	coconut palm	humid tropics	2.2
Persea americana	avocado	humid, semi-arid, highland tropics	2.2
Bertholletia excelsa	Brazil nut	humid tropics	2.0
Macadamia ternifolia	macadamia	humid tropics and subtropics	1.8
Attalea speciosa	babassu palm	humid tropics	1.5
Carya illinoiensis	pecan	temperate to subtropics	1.5
Attalea funifera	piassava palm	humid tropics	1.1
Olea europea	olive	Mediterranean	1.0
**Brassica napus*	rapeseed	cold temperate	1.0
**Papaver somniferum*	poppy	cold temperate, Mediterranean	0.9
**Arachis hypogaea*	peanut	worldwide	0.8
**Helianthus annuus*	sunflower	worldwide	0.8
**Oryza sativa*	rice	humid worldwide	0.6
Cucurbita foetidissima	buffalo gourd	cold to tropical arid	0.6
Corylus spp.	hazel	cold temperate	0.4

Perennial Staple Crop Profiles

Perennial staple crop profiles are grouped by family or in other clusters. This listing represents the “fruit” of several years of research, but represents just a sampling of the great diversity that is out there.

PALM FAMILY (*Arecaceae*)

The palms contain some of the world’s best-developed perennial staples. Indeed they rank among the most useful plants of the world. Palms as a group are very versatile multipurpose species, many producing structural materials like thatch, fibers, fodder, and non-edible fuel and industrial oils.

Coconut (*Cocos nucifera*) is among the most useful plants in the world. The nuts alone have dozens of uses. As a staple food they are very high in oil and provide important food energy to hundreds of millions of people around the coastal and humid lowlands tropics. Its tolerance of extreme winds and salty water make the coconut ideally suited to our changing climate. In addition to high oil yields, coconuts can produce 3-4 tons per hectare of copra (nutmeat) and over two tons of oil.

Date (*Phoenix dactylifera*) fruit has been a staple for millennia. Dates are very high yielding and store well. They provide a very high food energy value and are also high in vitamins and minerals. Though somewhat picky about climate, dates can be grown in many arid to semi-arid tropical and subtropical regions. Yields range from 11-17 tons per hectare.

Oilseed Palms. Many palms produce edible oils. In fact, according to my research five of the top ten edible oil crops in the world are palms. This elite group includes the African oil palm (*Elaeis guineensis)*, macauba palm (*Acrocomia aculeata*), buriti palm (*Mauritia flexuosa*), coconut, and babassu (*Attalea speciosa*). These species grow in a range of humid to semi-arid tropical and subtropical regions. These species yield from 1.5-5 tons per hectare of oil.

Peach Palm (*Bactris gasipaes*)**.** Peach palm was once a major staple in the Americas and has tremendous worldwide potential. The cooked fruits are an important food, high in beta carotene and carbohydrates much like orange-fleshed sweet potatoes. They can be dried into flour and stored for long periods. Yields are outstanding, from 20-30 tone per hectare. Peach palm should be much more widely grown in the humid tropics. Breeding work has resulted in some dwarf, spineless forms with superior ease of harvest.

Sago. This phenomenal group of palms, with *Metroxylon sagu* the most developed, represent a perennial staple crop that has already far exceeded the potential of most annual crops. Sagos are multi-stemmed palms. When a given trunk has matured to the proper stage, it is cut down and harvested without damaging the future productivity of the clump. Sago trunks are composed of carbohydrates and fibers. Processing (from stone age to modern techniques) removes the fibers and results in sustained harvests of no-till perennial starch. Once established (5-7 years), a sago stand can produce 25 tons or more of edible starch per hectare indefinitely.

Sugar Palms. The "official" sugar palm, *Arenga pinnata*, is a remarkable food producer. Of the world's many sugar-producing palms, it is perhaps the highest yielder and is grown commercially on a large scale. Flowerstalks are cut, and the sugary sap is collected, in a manner analogous to sugar maple but with much higher sugar yields, up to 25 tons per hectare.

LEGUME FAMILY (Fabaceae)

Annual dry beans and pulses (like lentils) are essential staple crops around the world. Though there are a few standout perennials like runner and lima beans, few efforts have been made to domesticate or improve promising perennial legume food crops. Most species profiled under this family also fix nitrogen, a major contribution to agroecosystem productivity. Mesquite, chachafruto, Tahitian chestnut and pigeon pea stand out as particularly promising. Many other trees with edible seeds and pods await development, notably *Leucaena edulis* and *Acacia, Parkia,* and *Pentaclethra* species.

Acacias (*Acacia* spp.). For the world's driest climates and poorest soils, these trees and shrubs offer a high-protein seed crop. Though yields are not fantastic (1.2 tons per hectare), they surely compare with most other crops that could be grown under similar conditions. And they have received little research and breeding attention. Note that though many acacias are toxic, these particular species have been eaten for thousands for years. Edible acacia species include *A. holosericea, A. murrayana,* and *A. victoriae.*

Carob (*Ceratonia siliqua*) is a traditional Mediterranean tree crop which has never reached its full potential. It is grown mostly as a livestock food. When I was a child, carob bars were promoted as a substitute for chocolate. I was not convinced. However, as an adult I have come to appreciate both the raw, whole pods and the flour as a very fine foods on their own merits. Carob prefers semi-arid subtropics and Mediterranean climates. It can be quite productive, up to 2-12 tons of pods per hectare. Unfortunately carob does not fix nitrogen.

Chachafruto (*Erythrina edulis*) is a phenomenal food plant. A nitrogen-fixing tree, easily propagated by live stakes, it produces enormous pods full of edible beans. Yields are very high – 13 tons per hectare (three to four times higher than soybeans), yet chachafruto has received little breeding attention and is difficult to even acquire for testing outside of its native Andes. This species should be in every backyard in the highland tropics. A stunning example of the potential of perennial beans.

Chipilin (*Crotolaria longirostrata*) is a Mesoamerican nitrogen-fixing shrub. The cooked leaves are a popular vegetable. They have a remarkable 38% protein dry weight and can produce 5-11 tons per hectare dry weight. Chipilin grows in semi-arid to humid tropics and subtropics, including highlands. This species should be much more widely grown.

Honey Locust (*Gleditsia tricanthos*) was proposed by J. Russell Smith in *Tree Crops: A Permanent Agriculture* in 1927 as a tree fodder for livestock and potential sugar or flour crop for people. Though little has been done to develop this crop, it remains the potential carob of the cold-winter world. Like carob, honey locust does not fix nitrogen. Honey locust pods are large and full of sugars in good varieties. They yield 3-15 tons per hectare though reports vary widely. It casts very light shade making it an excellent overstory crop for pastures or food forests. At least one nursery (Hidden Springs) offers grafted superior varieties.

Illinois Bundleflower (*Desmanthus illinoensis*)**.** This native US prairie herb has been the subject of domestication efforts by the Land Institute for decades. Land Institute breeders have had substantial gains towards developing non-shattering (seeds held in pod until harvest), higher-yielding, large-seeded varieties. The challenge they are currently facing is the poor flavor of the cooked beans, with several processing techniques under investigation.

Mesquite (*Prosopis* spp.) is among the finest of the world's perennial staple crops. These nitrogen-fixing species of arid regions are true desert survivors. Some species are quite cold-hardy and others are truly tropical. For millennia, people and livestock have consumed their sweet pods. The pods are nutritionally similar to wheat. Mesquite pods are utilized in many arid regions as fodder, though in the US they are destroyed to make way for pasture. Mesquite pods as human food are undergoing a resurgence. Dr. Richard Felger, a researcher associated with the Sky Island Alliance and the University of Arizona herbarium, has spent decades investigating the potential of this important and high-yielding desert food crop. He feels that within it will become a major world crop in the near future, and notes its tolerance of salt as well as drought. Tropical species yield up to 10 tons per hectare, with cold-hardy forms more like 2-4.

Perennial *Phaseolus* Beans. Several beans of world importance are perennials, notably lima (*P. lunatus*) and runner (*P. coccineus*) beans. In both cases vining pole types are perennial while bush forms are annual. Yields range from 3-5 tons per hectare. Both species are tender to frost, though Ken Fern of Plants for a Future reports that runner beans re-sprout and yield for twenty years or more in England. Tropical crop experts at ECHO have been distributing seed of the long-lived "7 Year" lima variety, which is adapted to very dry regions. Both runners and limas have potential to cross with the cold-hardy perennial US native *P. polystachios*, forming the basis of a perennial pole bean for the rest of us.

Pigeon Pea (*Cajanus cajan*) is already a legume crop of world importance, in humid to quite arid tropical and subtropical regions. However most varieties are grown as annuals, and most breeding work has focused on annual forms. Yields tend to be high the first year (1-5 tons per hectare), with plants persisting as shrubs for 3-5 years after with low yields if not plowed under. There is no reason not to focus breeding work on varieties that will continue to yield well for multiple seasons. Perennial types are already widely used in agroforestry and homegardens, and the ideal sustained-yield pigeon peas may already be out there in a hedgerow somewhere waiting to be put to use.

Tahitian Chestnut (*Inocarpus fagifer*) is a large nitrogen-fixing tree from the Pacific. It produces edible nuts, which can yield a remarkable 4-30 t/ha, and was apparently more intensively cultivated in the past. Of great interest to multistory polyculture enthusiasts, it is somewhat shade tolerant. Tahitian chestnut requires a lowland humid tropical climate with year-round rainfall.

MULBERRY FAMILY (Moraceae)
Many of our best perennial staples come from this family, particularly in the humid tropics and subtropics. These include species from Asia, Africa, and the Americas, and are grown for nuts, starchy fruits, sweet fruits, and vegetables. One species even produces an edible milk!

Breadfruit & Breadnut (*Artocarpus altilis* & *A. camansii*). Breadfruit is one of the few perennial staple crops to have reached it potential. It is widely grown in the Pacific but could and should become commonplace in humid tropical lowlands throughout the world. The large starchy fruits can be used in many ways, with a mix of varieties (Dr. Diane Ragone of the Breadfruit Institute has collected 120) fruit can be produced year round. Yields range from 16-30 tons per hectare. However, only 2-5 varieties ever made it out of the Pacific, so the world's perception of this fruit is limited. Breadnut is a seeded form of breadfruit with large, protein-rich nuts and outstanding yields (11 tons per hectare). We need a Breadfruit Institute for every one of the crops profiled here! The related African breadnut (*Treculia africana*) yields 5-10 tons per hectare.

Jakfruit (*A. heterophylla*) is a breadfruit relative with truly enormous fruits. When ripe, they are a first-class dessert fruit. When green (and already huge), they can be eaten as a starchy fruit much like breadfruit. The ripe fruits have large, high-protein edible nuts as well. Jakfruit is one of the highest-yielding foods in the world. It is more flexible than breadfruit as to climate, tolerating drier and more subtropical zones as well as lowland humid tropics. Yields are high, from 6-12 tons per hectare or more.

Ramon or Mayan Breadnut (*Brosimum alicastrum*). The ramon was once a staple crop of the Maya in Mesoamerica, complementing the corn harvest. The fruits are edible and enclose an edible starchy nut. Ramon is adapted to semi-arid to humid lowland tropics and yields 7-8 tons per hectare. The related "cow tree" *B. utile* produces a tasty milk-like sap that has been tapped and consumed for centuries.

Fig (*Ficus carica*)
The fig, along with dates, raisins, and dried mulberries, represents a class of dried fruits consumed as staple carbohydrates for centuries. Figs are productive, easily grown, and adapted to a wide range of subtropical and temperate climates. Note that there are many other edible *Ficus* species in the tropics and subtropics, including the sycamore fig (*F. sycamorus*), grown in Egypt for 5,000 years.

White Mulberry (*Morus alba*). White mulberry leaves are cooked and eaten in at least several areas of Latin America. They are very high in protein, and selected varieties have very good flavor and texture. Fresh leaf yields can reach an astonishing 53 tons per hectare. Much is known about coppiced mulberry leaf production as it is a critical fodder for silkworm production and also widely used as a fodder for other livestock. Now perhaps it will take its place as a human fodder as well. Some reports also indicate that dried mulberry fruit, along with hazelnuts, are or were the staple food of some Himalayan regions. They are delicious and filling, though information on nutrition and yields is hard to come by.

HARDY NUT CROPS
Cold-hardy nut trees and shrubs may yet not compare with tropical gems like breadnut and peach palm, but their sheer ability to survive vicious winters counts for a lot. I wrote in my previous article about Badgersett Research Corp's work to develop sophisticated new "woody agriculture" systems based on chestnut and hazel. It should be noted that a drawback to heavy reliance on nuts as food is the prevalence of nut allergies (though in their favor, nut consumption has been linked

to reduced incidence of heart disease). These species, along with perennial grains and honey locust, offer a respectable place to start for a perennial carbon-sequestering staple crop system for the cold world.

Chestnut (*Castanea* spp.) is a top-ranked cold-climate perennial staple with 3-5 tons per hectare yields. People in Asia, Europe, and North America consumed chestnuts as a staple for millennia. Yields today are higher than any other cold-climate nut crop. Chestnuts are high in carbohydrates and make wonderful flour for baked goods. This species, along with hazel (below) is the subject of intense breeding work by Badgersett Research Corp with the goal of replacing Iowa's corn and soybeans with woody agriculture.

Hazel (*Corylus* spp.) is the other strongest candidate for a cold-climate nut crop. Quick-yielding, high in protein and oil, hazels have made great progress under the Badgersett breeding program. Among the many species and hybrids are forms that thrive in very cold and semi-arid to humid climates as well as Mediterranean regions. Nut yields range from 2-4 tons per hectare. Hazels also have promise as oilseed for cold areas yielding 0.4 tons per hectare.

Nut Pines (*Pinus* spp)**.** Many species of pines from Europe, Asia, and the Americas produce edible nuts. Though yields are not high and are often not consistent from year to year, many nut pines, particularly the American and Mexican pinyons (*P. edulis, P. monophylla, P. cembroides*) tolerate terrible soils, very dry conditions, and extremes of heat and cold that would shrivel almost any other crop. Though slow to come into mature bearing, nut pines have been the staff of life for many peoples for thousands of years.

Oaks (*Quercus* spp.). Acorns served as a staple human food for millennia. Challenges to oak domestication include bitter tannins in acorns and a strong tendency to bear heavily one year and then very lightly for several years. On the other hand oaks hybridize readily and can be propagated by grafting once a new variety is developed. In Europe and the Mediterranean, ancient selection has provided us with low-tannin forms of *Q. ilex*, which however do not yield terribly well (1-2 tons per hectare). Efforts at oak breeding in the US go back to the first parts of the 20th century. Oikos Tree Crops leads the pack today in developing and offering higher-yielding, lower-tannin, more regularly-bearing hybrid oaks. Though the perfect oaks for human food have not yet been developed, we are on our way there.

Pecan and Hickories (*Carya* spp.)**.** Pecans are native from Michigan to Mexico and yield well in warmer cold temperate regions as well as some subtropical areas. These long-lived and enormous trees are excellent for carbon sequestration. Though pecans are only moderately high yielders (3 tons per hectare), due to their high oil content they are among the best cold-climate oilseeds (1.5 tons per hectare).

Walnut (*Juglans* spp.). Many species of walnuts are cultivated, from the tropical highlands to cold and Mediterranean climates. *Juglans regia* is the main walnut of commerce. The nuts are high in fat with respectable protein. For centuries yields of 2.5 t/ha were close to the limit. The development of new, precocious, lateral-bearing varieties adapted to intensive production has permitted yields as high as 4.5 tons per hectare.

PERENNIAL GRASSES (Poaceae)
Perennial grains are still a decade or more in the future, though thanks to the visionary work of the Land Institute and others, we are already decades closer to achieving that goal. Both perennializing annual grains and domesticating wild perennials present serious breeding challenges. However, perennial grains have multiple benefits – they are widely adaptable to climates and soils, and their harvest, processing, and consumption are familiar to millions.

Corn (*Zea mays*) has perennial relatives and can also be crossed with hardy perennials including Eastern gammagrass (*Tripsacum dactyloides*). Work at the Land Institute has made substantial progress towards developing perennial corn. Land Institute breeders report that with sufficient funding a perennial corn could be ready for field tests in as little as ten years. One challenge is that the perennial rhizomes that overwinter the plants are not cold hardy, so breeding is focused on deeper rhizomes that survive below the frost line. Of course this consideration is not important in the tropics where millions of people rely on corn as a staple.

Indian Ricegrass. This perennial North American native (*Oryzopsis hymenoides*) was a major staple to indigenous peoples of the west. Discovery of a non-shattering clone allows it to be grown today on a commercial scale in Montana, producing a specialty gluten-free flour. High prices make up for low yields. Little breeding work has been done of this drought- and cold-tolerant perennial grain.

Intermediate Wheatgrass. The Land Institute has been working for several decades to domesticate this perennial wild grain (*Thinopyron intermedium*). They have had relatively rapid success, and intermediate wheatgrass is currently undergoing a 30-acre field trial. The research fields are burned annually to control weeds, and apparently the crop can also be grazed to provide a non-seed yield. Production is still low, though researchers aim to see it reach one ton per acre.

Nypa (*Distichlis palmeri*) is a perennial salt-tolerant grass of the Sonoran desert deltas. Nypa grain flavor is apparently excellent. Once a staple of the Cocopa people, this species became virtually extinct. Dr. Richard Felger, a researcher associated with the University of Arizona herbarium and the Sky Island Alliance, has worked on developing nypa as a salt-tolerant perennial grain for decades. Though there were some efforts to commercialize the crop too early, Felger feels that it will become a major world crop comparable to short grain rice in grain size and flavor.

Rice (*Oryza sativa*). Rice has several perennial relatives, one an African perennial rice and the other actually a strain of the wild ancestor of annual rice. Under some conditions, some annual rice plants will "rattoon" (re-sprout) for several years.

Perennial rice breeding work was carried out at the International Rice Research Institute in the Philippines in the 1990s, and was picked up by the Yunnan Academy of Agricultural Sciences in Kunming, China in 2007. Perennial rice breeding is very challenging and many factors need to be overcome before field testable material is available. The current focus is on replacing annual upland rice, which is grown on steep slopes, as opposed to irrigated paddy rice, which is grown in terraces or level fields.

Sorghum *(Sorghum bicolor*) is weakly perennial in the tropics and "rattoons" or re-sprouts for several years in ideal conditions. Perennial sorghum breeding at the Land Institute has focused on crosses with the perennial weed Johnsongrass (*S. halipense*). Like corn, there are challenges in overwintering tender rhizomes, which would not be an issue in the tropics. Perennial sorghum is farther along than most of the other perennial versions of major grains but is not yet ready for prime time. Perennial sorghum could be bred not just for grain but also for syrup, which was once made from the stalks across the American Midwest. Sorghum is very versatile in terms of climates to which it is suited, but it is particularly appropriate to dry regions where it can outperform corn.

Sugarcane. This perennial (*Saccharum officinale*) is the source of more than half of the world's refined sugar. Though conventional monocultures of sugar cane are environmentally undesirable, and most producers manage it as a short-lived perennial, this species has a place in responsibly designed and managed perennial polyculture systems.

Wheat (*Triticum aestivum*). Perennial wheat breeding efforts began in the Soviet Union almost one hundred years ago. Only with recently developed techniques is perennial wheat breeding beginning to show results. Several universities are working alongside the Land Institute on perennial wheat breeding including Washington State. One variety has yielded as high as 5.8 t/ha (a commercial annual variety yielded 9 t/ha in the same trial) in eastern Washington. The Land Institute has had no success in perennial wheat survival in Kanasas (nor have I in Massachusetts). In Australia some perennial wheats, despite low grain yields, have been shown economically feasible when sheep are grazed on the wheat fields in the off season.

BANANA FAMILY (Musaceae)

This family currently provides staple fruits for hundreds of millions of people, and with wider utilization of enset these numbers could increase. Though heavy feeders and drinkers, bananas and plantains can be incredibly productive starch sources. The plants themselves are also multipurpose sources of fodder, biomass, paper, fiber, and wrapping materials.

Bananas & Plantains (*Musa acuminata* & *M. paradisica*) are perennial staples that hundreds of millions of people rely on for their daily food. With sufficient fertility and water bananas and plantains can outyield almost any other crop. Though thousands of varieties are grown, commercial production is focused on a handful of clones. Industrial banana production has been a major contributor to social and ecological problems, but in integrated agroecosystems these staple fruits can play a very positive role. In ideal conditions they are among the highest-yielding starch crops at up to 60 tons per hectare.

Enset *(Ensete ventricosum*). Domesticated enset, distinct from ornamental cultivars, is an important staple in the Ethiopian highlands, where 10 million people rely on it. Outside of Ethiopia it is little known. Enset is a banana-like plant, with huge (1m x1m) starchy tubers and enormous (1m x 3m) starch-filled trunks. This starch is processed into many products including fermented *injira* bread. Harvest of the whole trunk results in several hundred sprouts from the base. Families manage enset patches with plants of different ages. A single plant can feed a family of five for a month. Processing the starch is labor intensive and work is needed on appropriate technologies for enset processing. Yields are around 5 tons per hectare dry starch.

YAM FAMILY (Dioscoreaceae)
The species profiled here (along with some other species and varieties of *Dioscorea*) is almost unique among tubers in that they are produced above ground, on the vines. This allows no-till production and harvesting of storable tuber crops, giving this species unique potential in carbon-sequestering agriculture. Though air potato is the only species profiled from this family, it is worthy of a prominent place in the perennial staples palette.

Air Potato (*Dioscorea bulbifera*) is a tropical and subtropical supercrop, with select forms producing large edible aerial tubers at rates of up to 19 tons per hectare. At the Las Cañadas permaculture center in Mexico, air potato is proving itself to be productive, delicious, and well behaved when trellised on established nitrogen fixing trees. Though opportunistic toxic forms have naturalized widely, earning the species a poor reputation, edible forms are less aggressive. The native range of air potato stretches from Australia to Africa, thus even if serious efforts at air potato production were confined to that area it could make a tremendous positive impact. The day may soon come when a web search on air potato mostly turns up the environmental costs of *not* growing air potato.

TROPICAL AND SUBTROPICAL NUTS
This is just a selection of the many potential species. These species may only stand out because yield data is available. Like cold-climate nuts, these have the drawbacks of nut allergies and processing issues. Some tropical nuts are remarkably productive. See also Tahitian chestnut and breadnut and its relatives (above) and Brazil nut (below).

Almond (*Prunus dulcis*). This Mediterranean nut crop is high in oil and protein, and widely enjoyed. It is one of the most widely grown nut crops, with large-scale production techniques worked out. Almonds have been cultivated for at least six thousand years. Yield are high at up to 4 tons per hectare.

Canarium Nuts (*Canarium* spp.). This genus of underutilized nut trees from Asia and the Pacific produce good yields of high-fat nuts. They are adapted to the lowland tropics, and are a component of ancient agroforestry systems in Melanesia. Canarum nuts have received little research attention but have great promise.

Macadamia (*Macadamia integrifolia*) is a recently domesticated Australian species that has become globally popular. Macadamias prefer humid subtropics but are fairly adaptable. The nuts are very high in fat, in fact they are an excellent oilseed. Nut yields are very high in the right conditions, 4-6 tons per acre and 1.8 tons of oil.

Marula. This African tree (*Sclerocarya birrea*) is a remarkable food plant from tropical and subtropical arid lands. A mango relative, marula produces a tart edible fruit with a remarkably nutritious nut inside. Fruit yields of 4.5 tons have been reported from a single superior tree, though the nut yield is much less due to thick shell and small kernel size (extrapolated to 2 tons per hectare). The macadamia-like nuts are high in protein and an oil of very high quality. This species is virtually untouched by modern plant breeders, and is in need of development of simple processing technology to facilitate the difficult removal of the nuts from their shells.

Oyster Nut (*Telfairia pedata)* is a tropical African perennial cucurbit. Oyster nut vines produce football-sized fruits full of edible nuts. The yield of these nuts is high, 3-7 tons perhectare. Oyster nuts are high in oil and protein, taste excellent, and can be stored up to eight years. This species is quite weedy but should at the very least be developed and utilized in its native range. It is grown in sophisticated agroforestry systems in east African highlands.

Pandanus or screwpine is a widespread tropical genus, including species grown for edible nuts, fruits ("keys"), and as a culinary herb. New Guinea highland people domesticated karuka (*P. jiulianettii*) perhaps thousands of years ago - New Guinea is one of the independent centers of plant domestication and farming there may date back more than 9,000 years. Karuka nuts are a very important food in the highlands from 1800-2500m altitude.

Pistachio (*Pistacia vera*) is an important commercial nut for hot, dry areas with some winter chilling hours. Though yields are not extremely high and trees alternate heavy and light bearing years, pistachios are high in fat and a good food energy value, especially given their ability to thrive in difficult climates. Yields can reach 3 tons per hectare.

PERENNIAL OILSEEDS

Many excellent oilseeds are also profiled in the palm, hardy nut, and tropical nut sections above (and avocado below). Fats from oilseeds are an important part of a healthy human diet, though some are much healthier than others – African oil palm oil being on the low end and olive oil on the high end. See the table of comparative oilseed yields to see that perennials generally far outproduce annuals. This is one category where, at least in the tropics, perennials are already in "prime time."

Brazil Nut (*Bertholletia excelsa*) is a Amazon rainforest canopy tree. The nuts are harvested commercially from wild stands, but yields in plantations are poor, reportedly due to the lack of diverse pollinators in monoculture systems. The nuts are high in oil – up to 70%. Thus though yields of nuts per hectare are not extraordinary, this is among the highest-yielding oilseeds on the planet (2 tons per hectare)– and perhaps completely undomesticated.

Buffalo Gourd (*Cucurbita foetidissima*) is a perennial squash of arid lands in North America. It is tolerant of both intense cold and heat. Though the fruit is hard and bitter, the seeds are edible much like cultivated pumpkin seeds. The seeds are the source of an edible oil and are high in protein. Buffalo gourd domestication and cultivation efforts have been under way for several decades. Seed yields reach up to 3.4 tons per hectare, with 0.6 tons of oil.

Inche (*Caryodendron orinocense*). Yet another Brazilian oil tree with dazzling potential and little domestication attention, inche is a tree of semi-arid to wet tropics. Oil yields are very high (3 tons per hectare), and may someday compete with African oil palm. The nuts are also edible.

Okra (*Abelmoschus esculentus*). While okra is primarily grown as a pod vegetable, it has many other food and industrial uses. The seeds are analogous to soybeans in that they are high oil (40%) and high protein (though the seeds may need some processing to remove toxins before the protein is fully available). A team led by Dr. Frank Martin made a high-protein and delicious tofu from okra seeds in the 1970s. The oil is of high quality similar to olive oil, and yields are about half those of oilseed sunflower even without any breeding work for oil production. Perennial forms up to 15' high are found in the African tropics and could be the basis of a multipurpose perennial soybean analog.

Olive. Olives (*Olea europea*) are the standard against which other oil crops are measured. Quality is excellent, and yields are fairly good (1 ton per hectare). Olives can grow in dry, infertile soils. Trees can live a thousand years or more – a great example of "permanent agriculture." Primarily adapted to Mediterranean climates, though a few varieties can be grown in cool maritime temperate regions.

Pequi (*Caryocar brasiliense*) is a multipurpose Brazilian savannah tree. It is widely grown for its edible fruit and nuts. An edible oil is pressed from the nuts. Pequi is one of the highest-producing oilseeds in the world (3.1 tons per hectare). Little if any modern breeding or crop development work has focused on this species.

Sunflower. Annual sunflowers (*Helianthus annuus*) are a very important world oilseed crop. The genus *Helianthus* is large and has many perennial species that can cross with *H. annuus.* Land Institute breeder David van Tassel has been working to develop perennial grain sunflowers for several decades, using Maximilian sunflower (*H. maximiliani*) as a component of their blend. This perennial species is particularly interesting as it has wide adaptability and is allelopathic (produces natural herbicide to prevent weed germination).

NUTRITIOUS FRUITS

Many fruits provide nourishing, high-energy staple foods. This is an area I am just beginning to explore. Only a few promising species are profiled here. Persimmons, raisins and other dried fruits, and the many rich, filling fruits of the Sapotaceae are all potentially candidates. See also date and peach palm, breadfruit and its relatives, and bananas and plantains (above).

Avocado (*Persea americana*) is very productive and has a high food value. The fruits are very high in oil and high in protein for a fruit. In fact avocado ranks very high globally as an oil crop. Fruit yields have reached 32 tons per hectare in ideal conditions with 2.2 tons per hectare of oil. Between the different races of avocados are forms adapted to high and lowland tropics, from semi-arid to humid regions.

Butterfruit (*Dacryodes edulis*) has been billed as the African answer to the avocado. High in protein and fat, this tree grows from semi-arid savannahs to rainforest understories. Fruits must be briefly heated before eating, and have a sour and slippery taste experience that takes getting used to. This species has been getting a bit of development attention in recent decades and has great potential to address food security particularly where low-protein starchy staples like cassava and corn dominate the diet.

Chayote (*Sechium edule*). This perennial squash is a common vegetable throughout the tropics and subtropics. The varieties sold in the US are watery and not terribly nutritious. However, in Guatemala (where chayotes were originally domesticated), there are a great variety of forms. Some, including spiny-fruited types and white *peruleros* are very filling, almost like potatoes. These varieties should be investigated for staple crop potential and distributed more widely.

Lucuma (*Pouteria lucuma*). This Andean native tree, though it has received little attention from scientists, is a productive (1,000 lbs/tree and an extrapolated 14-16 tons per hectare) and low-maintenance crop. The fruits taste something like sweet potato with maple syrup, and are filling and nutritious. Fruits are borne year-round and are essential in years that annual crops fail. Lucuma fruits can be processed into flour that lasts for years. The trees are somewhat picky about climate, preferring mesic or semi-arid tropical highlands or other cool tropical climates like some coastal areas.

HIGH PROTEIN LEAF CROPS

This is a category of perennial staple crop little exploited as a food resource, but with great potential. Though they are of value fresh or cooked, often these leaves are dried to make a storable, high-protein concentrate. Note that not all protein in these crops may be digestible. Most of these species are coppiced for intensive production. See also mulberry and chipilin profiled above.

Baobab (*Adansonia digitata*) is an undersung hero of arid Africa. This multipurpose species has edible high-protein leaves, with a nearly perfect amino acid balance. Perhaps we have been eating baobab since we were *Australopithecus*. Baobab also produces nutritious nuts and a dry fruit that can be made into flour and stored for several years. The trees have dozens of other non-food uses as well.

Chaya (*Cnidoscolus chayamansa*), or Mayan spinach, is a shrub of the tropics and subtropics. It tolerates arid to humid conditions, in lowlands and highlands. Though raw leaves contain cyanide, the cooked leaves are very nutritious. Yields are very high, 20-30 tons per hectare fresh.

Katuk (*Sauropus androgynous*) is an Asian shrub with delicious leaves. Unlike most woody leaf crops it can be eaten raw. It likes humid tropical lowlands and thrives in the shade of fruit and nut crops. The protein content of fresh leaves is 6-10%.

Moringa *(Moringa oleifera, M. stenopetala*) is a small tree of the tropics, thriving in arid and humid climates. The dried leaf is incredible nutritious, and used by nursing mothers in much of the tropics. If allowed to grow to tree form moringa produces nutritious pods, but for leaf production it is coppiced. Yields of moringa leaf are very high, 10-50 tons per hectare.

Summary

When I first became interested in food forest systems twenty-one years ago, it was simply because they seemed unbelievably cool. Today they have moved from a really cool idea to one that may be essential if we are to prevent catastrophic climate change. It is my hope that the preliminary palette of sixty-two genera presented here makes the case for the potential of "permanent agriculture" based on perennial staple crops, and catches the reader up on key players and developments in breeding work.

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