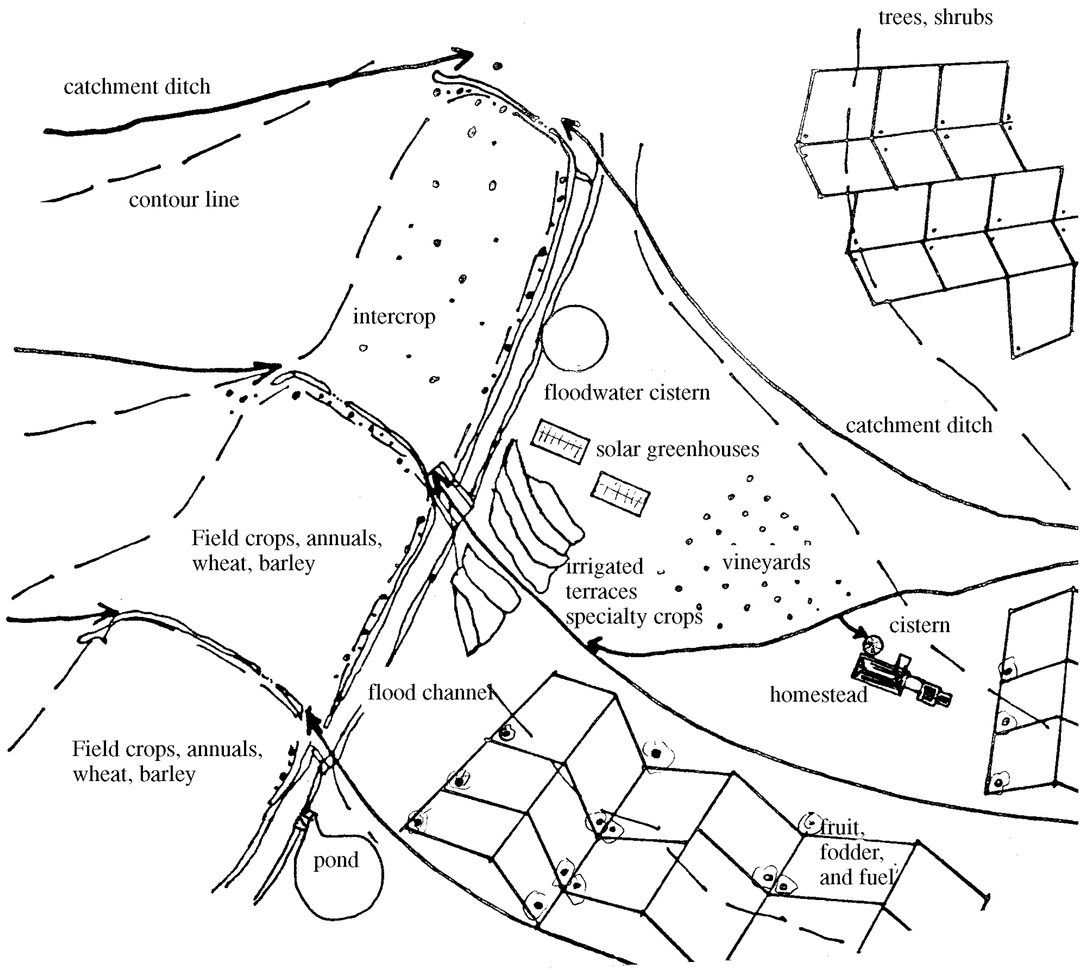
Self-reliant Agriculture for Dry Lands



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Sierra Nature Prints

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Dedication:

To the intelligent and observant people who have successfully and sustainably managed the dry lands of the world and developed many little known but invaluable cultivars and techniques for thriving under very difficult conditions.

Acknowledgments:

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1. The problems is.....

One in seven people in the world live in semi-arid and arid regions. These people (more than one billion) are both cause and victim of increasing degradation of these fragile environments. Almost 2 in 3 of these people have been affected by the direct and indirect affects of deteriorating conditions, including insufficient or contaminated drinking water, inadequate calories and vitamins, inadequate fuelwood for cooking, and insufficient material for building. More than 30 million square kilometers of the World's drylands are deteriorating under this pressure with serious and often tragic consequences for their inhabitants.

Yet despite the magnitude of this problem little research has been undertaken to help these low-input dryland farmers. Most of the research and development work on drylands agriculture has emphasized irrigated, high-input, intensive (expensive) production farming of commercial crops (wheat, corn, etc.) in monocultures. The focus on high yield with little concern for high risk and unsustainability has led to many environmental and economic tragedies. This paper addresses the vast majority of dryland dwellers who are and will remain small family farmers growing most of their crops for personal use. These farmers must use water and biological resources efficiently and carefully to minimize risk and achieve moderate, reliable yields.

Much can be learned from the traditional gathers and farmers of the Worlds drylands. These intelligent and hard working people have demonstrated the possibility of establishing stable, healthful, and enjoyable livelihoods in areas with less than 200 mm (8 inches) of precipitation a year, and as little as 75 mm (3 inches). With well planned water collection and management, careful selection and care of crops, and skillful design of buildings and facilities these practices can provide a sustainable living for the dryland dwellers of the world.

This paper provides a brief review of some of the key issues required for sustainable resource management in dry lands. References are provided for follow-up reading. Research is urgently needed on many topics, to better understand the successes of various groups and to adapt them to new cultivars and environmental conditions.

"The Papago Indians, by several hundred years of desert experience, are thoroughly conversant with the conditions in their country and with consummate judgment have so located their charcos and fields as to secure maximum results from the limited rainfall available. We cannot go into their country with the idea of teaching them farming or irrigation under conditions as we find them in other parts of the country. Any attempt to introduce modern farming methods, as we understand them elsewhere, would result in disaster." Clotts, 1917.

The key resource management questions of the dry lands are -- water, food, and shelter.

2. Water

Skillful water management is the key to survival in the drylands. Rainfall is often erratic and may include intense, brief storms in summer and gentler storms with rain or snow in the winter. Settlement in very arid regions can be successful with appropriate design of water collection and storage systems and efficient water use. The Nabateans successfully farmed over 300,000 hectares of the Negev Desert highlands (rainfall <100 mm/yr) in Roman times using refined runoff designs and the indigenous people of the Southwestern United States have grown corn for more than a thousand years in areas with less than 150 mm (6 inches) of rain per year.

Combining the skill and understanding of these highly evolved and skilled cultures with modern materials, scientific knowledge, mechanical equipment, and improved ability to select and modify plant materials (from around the world) has made it easier to develop sustainable practices for managing these dry lands. Methods to encourage and reinforce cultural attitudes that foster environmental conservation can also be learned from some of these cultures.

The emphasis of most subsistence farming should be on rainfed agriculture with only limited use of super-efficient irrigation methods. Rainfed agriculture is less likely to cause soil salinization than irrigated farming and is much less costly. It can be developed and managed without vast inputs of capital and energy for dams, canals, pumps, and wells.

The most common elements of rainfed agriculture are: conservation farming, use of microcatchments and concentrating systems, and sophisticated runoff management and irrigation systems in more arid areas.

A. Conservation Farming

The essential ingredients of water conservation in farming are: managing soil to minimize runoff and evaporation using a combination of tillage, surface shaping, mulch, and fallow; weed control to minimize unwanted evapotranspiration (uncontrolled weeds may consume 0.5 cm soil water per day); and timing crop production to maximize chances of success.

The Western United States and Canada include more than 100 million hectares of dryland farms using water conservation practices (precipitation of 150-800 mm/yr). These lands produce primarily wheat and other small grains, yielding 1-3,000 kg/hectare with intensive management (equipment, fertilizer, and biocides). The environmental costs are high: severe wind and water erosion, salinization and formation of saline seeps, and contamination of the environment from biocides (particularly herbicides and pesticides) and chemical fertilizer. Despite these problems, much can be learned from the extensive research that has been conducted here. Many of the experimental techniques which have largely proved unworkable in commercial production--vertical mulching and various terracing and micro-watershed management systems--can be of value to the small-scale family farmer.

a. Vertical mulching

Vertical mulching has been very successful in increasing infiltration of rainwater and reducing erosion. This has been done both by machine and more commonly by hand. Bundles or lines of straw, reeds, or other materials are arranged along the contour or in a checkerboard pattern.

b. Terracing

Terracing is one of the most common responses to erosion and runoff retention. Although most people are more familiar with seeing the terraced rice paddies of China and Indonesia, similar enormous investments of labor are made to develop terraces for grains and crops in dry lands ranging from Yemen to China. Terrace development utilizing trees and shrubs to help build and maintain the terraces is not widely known but is effective in many situations

c. Ridging

Ridging provides many benefits, including water collection and development of a microsite gradient that should provide favorable conditions for seeds over a wide precipitation range. Ridging is also very effective in areas that experience waterlogging or standing water at certain times of the year. Ridging also modifies the microclimate and can improve early seed germination.

In areas adversely affected by low infiltration or compaction a deep ripping on the contour will help address these problems and create long lasting ridges.

d. Mulching

Mulching and composting can also provide many benefits. Native grasses with seed are excellent for mulching if they are available; but straw is also of value. High application rates with crimping or tackifiers to retain the straw are desirable, particularly on erosive slopes. Compost is very effective, but in drylands it must commonly be made in pits to retain moisture. These can be incorporated in orchards and gardens.

e. Conservation tillage

The traditional plows of the drylands, the ard, which goes back before Roman times, stirred the soil without inverting it. This is important in arid lands where soil fertility may decrease rapidly with depth. This also conserves moisture. Mechanized conservation tillage is increasingly used on fragile lands. Conventional clean plowing practices that invert the soil are being replaced by tillage equipment that leave stubble or plant material on the surface to reduce wind and water erosion. Ridge tillage and strip cultivation can provide similar benefits.

f. Weed control

Weed control is important to conserve moisture. Soil solarization, which uses solar energy to kill weeds, weed seeds, and pathogens in soils and soil mixes, is very effective in sunny, hot dry lands. Solarization is often much better than using herbicides, fumigants, and other hazardous and expensive pest control methods. Farmers of the Deccan plateau in India have long exploited a form of solar soil heating to control weeds. They plow the weedy soil just before the hottest summer period when maximum daily air temperatures usually exceed 40°C, then leave it fallow long enough for the high soil temperatures to kill many weeds, weed seeds, and soil pathogens.

This technique is effective for bare soil only when the air temperatures are high and solar radiation is intense. The addition of a single layer of clear plastic can greatly increase heating and provide good control of weeds and pathogens in sunny areas where average maximum air temperatures approach 30°C for at least four weeks during the summer.

Recent studies at San Diego State University and Tuskegee University have demonstrated that increased temperatures can be reached with second layer of plastic (bubble-pack worked well at SDSU). This makes it feasible to solarize soil in cooler periods and with lower sun angles. Improved heating can also reduce the treatment time by as much as 50%.

The influence of these high temperatures on weeds, seeds, and pathogens is complex and not fully understood. Solarization can be an effective tool in the struggle to control the weeds that take up a large percentage of small farmers field work and reduce crop yields.

Deep rooted, heat tolerant weeds with rhizomes are usually suppressed but may not be killed by a single treatment. Adding compost and other soil amendments may improve control of the more resistant weedy species by increasing microbiological activity in the soil.

The effectiveness of soil heating in reducing or eliminating common plant pathogens such as *Fusarium*, *Verticillium*, and root rots has stimulated most of the research on soil solarization. Control of some insect pests has also been noted. One of the pleasant side-effects of solarization is more rapid plant growth in treated soil. This effect exceeds the benefits provided by pathogen and weed control and probably reflects a number of interacting benefits including increased nutrient availability.

Solarizing soil

Soil should be solarized during the hottest part of the year. Soil temperatures greater than 40°C for several weeks are desirable. Two or three soil thermometers at different depths will provide a good indication of how well the soil is heating. If soil temperatures are not reaching 35-40°C a small test plot (5 sq. m.) of doubled plastic can be monitored to determine the potential soil temperature rise with a second layer of plastic.

Cultivate the area thoroughly and then level the surface, removing stubble, sticks, and stones that can tear the plastic sheeting. Apply 2-3 cm of irrigation water to dry soils if possible, just before laying the polyethylene sheeting. The moisture improves the heat capacity of the soil and increases heat transfer. Fertilizer and soil amendments may be applied before the plastic is laid. Some soil amendments have improved the weed and pathogen killing effect of solarization.

Apply sheets of clear (not black or colored) 2 mil polyethylene (4-6 mil in windy areas) when it is least windy. The plastic will flap less if it is smooth and in contact with the surface. The thinner plastic lets more solar energy through but is relatively fragile. Use wide sheets to minimize joints and place the edges of adjacent polyethylene sheets in furrows and cover them with soil. Bury the free edges, and compact the soil around the sheets to reduce the loss of heated air and moisture. Place weights 2-3 m apart on the sheeting to prevent the plastic from flapping and tearing in the wind. Rounded river stones or small soil or sand filled plastic bags (fist-sized) can be gently placed on the plastic. When planning the layout leave sufficient space for access and drainage, either to a drain channel or to other plantings. Solarization may provide double benefits when it is used to concentrate the runoff from the plastic for crops or trees.

The polyethylene sheeting should be patched with tape if holes develop. Although farmers in the developed countries often plant into holes punched in the sheet, stronger plastic can be removed and reused for several seasons. If the soil is too wet when the plastic is removed let it dry to a workable texture before planting. If you cultivate after treatment, keep cultivation shallow (preferably less than 5 cm) to avoid moving viable weed seeds from the deep soil to the surface.

Soil solarization does not work against all weeds and pathogens, requires the use of chemicals and energy to make the polyethylene, and eventually leaves a plastic waste for disposal. But it is much cleaner and safer than herbicides and fungicides and often as effective.

Soil solarization can also be very effective in preparing soil mixes for container or garden plant production. Higher temperatures can be reached if the soil mix is treated on an insulated base.

B. Microwatersheds and Microcatchments

Microwatershed systems include mound and strip collectors. Strips can be built with mechanical equipment or by hand. The strips are bordered on each side by ridges from 3-16 feet (1-5 meters) apart. The result is a series of linear strips well suited for crops such as corn. In mound systems the soil surface is shaped by hand into 4-20 inch (10-50 cm) tall mounds spaced 1-5 meters apart. When organized into a regular pattern, this system is suitable for many types of farm crops, including melons and squash.

A gently sloping plain (ideally with slopes less than 5%) can be divided into plots by small earth ridges 4-8 inches (10-20 cm) high and 8-12 inches (20-30 cm) wide. The ridges are constructed with the soil excavated from a planting basin about 16 inches (40 cm) deep. The ridges can be constructed by hand or with a small plow.

The waffle gardens of the Zuni people are a combination of ridge and strip collectors that look much like a waffle print. The ridges are packed smooth and serve as walkways and water runoff areas.

Microcatchment basins of various designs have been used for thousands of years. These basins concentrate precipitation where the crops will be grown. Experiments have shown that under arid conditions a higher relative water yield can be achieved with small rather than large catchment areas. Smaller areas are also easier to build with limited equipment and labor and less likely to fail during intense storms.

Microcatchments have been used continuously in South Tunisia since they were introduced by the Phoenicians. Over 10 million olive trees are cultivated in this area. Microcatchments have also been used with considerable success in Israel, Mexico, Africa, and the Southwest U.S.

The gradients of the microcatchments should fall between 1-7%. Square or rectangular plots are most commonly used. They can be built by hand or with equipment. Protective diversion ditches are often constructed above catchment areas in areas subject to extensive ground flow. Trees or shrubs are not planted at the bottom of the basin but on a mound or on the ridge to prevent water-logging problems when the basin is full.

Yields from microcatchments can be estimated if the average annual rainfall, peak rainfall intensity, and the minimum expected annual precipitation are known. Site factors, including the runoff producing potential; the soil surface condition (cover, vegetation, crust, stoniness); the gradient and evenness of slope; and the water retaining capacity of the soil in the root zone profile are also important. Other factors affecting the infiltration capacity of a particular area include: the moisture content of the soil; macro-pores in the soil as a result of decaying roots or burrowing animals; and the compaction of the soil.

Normal precipitation for the area where the catchment is planned, the soil quality, and the slope, the size and depth of the planting basin in relation to the size of the catchment area, and other factors determine the size of the surface area wetted by runoff and the volume and depth of the water column in the soil. If a shrub requiring 30 inches of rain per year is being grown in a region of 15 inch average annual precipitation, then an additional 15 inches of rain is needed. If the catchment soil has a runoff of 10% (a typical runoff volume for untreated desert soils), then a 1000 square foot catchment should yield enough water to meet the water requirement for the shrub.

Removing vegetation commonly increases the runoff by decreasing the infiltration rate. Surface infiltration capacities are commonly proportional to vegetation cover, so as vegetation cover decreases infiltration decreases. This results in greater volume, depth, and runoff velocity. The development of biological surface crusts has considerable potential for increasing runoff in microcatchment basins. These cryptogamic crusts can decrease infiltration and increase runoff.

Several runoff enhancing treatments have been evaluated on microcatchment basins. Paraffin can be applied to the basin soil by hand, in the form of granules, at a rate of one to two pounds per square yard. Paraffin will melt within a few days in the hot desert environments to form a solid wax covering on the soil surface. The wax treated soils yielded 90% runoff compared to 10-30% runoff on untreated soils, and close to 100% runoff from a butyl covered plot. Wax treatments are best for sandy soils, and some plots have remained effective after five years, sufficient time for tree or shrub establishment.

Many types of synthetic membrane materials have also been used. Plastic membranes, such as polyethylene and vinyl, are effective but generally last less than two years. These materials have been used on extensive revegetation projects in China. Butyl rubber and chlorinated polyethylene sheeting lasts much longer, but these materials are more expensive.

Rock formations, packed earth, plastered areas (including indigenous manure/clay plasters), asphalt, concrete, and other hard surfaces can also be used to channel water to catchment basin plantings. The catchment systems developed in Australia for watering stock, particularly the roaded catchment, can very useful for the small farmer. Precipitation enhancement can enable the farmer to grow crops that would not survive otherwise. These may be cash crops or preferred foods for vitamins or calories, such as citrus, olives, apples, apricots, or grapes.

The effectiveness of catchments may be improved by digging pits near the crops and filling them with organic matter. These in effect, become compost pits (as anyone who has lived in a dry arid area this is one of the only ways to get compost to work) and fertilizer sources. They also get water down and out of the evaporation zone. This has been developed to its greatest extent in India.

C. Pitting

Other low-cost techniques that have been successful include the use of disks that have been modified to create pits which provide a variety of microsites and collect water. Pits may be made 30-60 cm (1-2 feet) wide and long and 15-20 cm (6-8 inches) deep. Larger pits may be more effective than small pits in very arid areas. Pits are most effective on slopes of less than 8% where natural infiltration is limited. These can also be dug by hand, using a large hoe. A team of people can pit a large area in one day. If seeds are placed in the pits good establishment of plants may occur. These are very effective for revegetation of denuded areas as treatment cost per acre can be very low. They have been used most widely in Australia.

D. Imprinting

Imprinters are heavily weighted rotating drums that force angular teeth into the soil surface. These teeth marks form the fluid exchange funnels that facilitate rainwater infiltration. The imprinter doesn't make continuous furrows that can concentrate and channel rainwater and move topsoil and plant residues from even gently sloping hillsides. The imprinter establishes interconnected water shedding and water absorbing imprints.

Seed germination and seedling establishment can both be improved by imprinting. Funnel-shaped imprints concentrate water, seed, litter, and topsoil together where these resources can improve seed germination and seedling establishment. The imprint also provides an improved and protected microsite to shield tender young plants from the desiccating effects of the hot sun and dry winds.

E. Runoff farming

Very sophisticated methods of runoff farming have been developed and used in Jordan, Yemen, the Negev Desert of Israel, Mexico, North Africa, Australia, and the American Southwest. These systems include a variety of techniques, including: 1) contour ditches to collect slope runoff -- with or without treatment to increase runoff; 2) dams of brush or stone to raise stream water high enough to fill side ditches which irrigate adjacent fields; 3) check dams of brush or stone to hold water long enough to fill field capacity; 4) planting in alluvial fans where water is naturally concentrated; 5) planting alongside or using water naturally concentrated by rock outcrops; and 6) planting directly in the water course as the water level falls, and 7) planting in washes and arroyos and accepting the risk of loss in a flood.

The traditional farmers of the Southwestern North America may have farmed successfully for hundreds and in some cases thousands of years with modest environmental decline. These skilled farmers have much to offer small farmers in other lands who wish to increase production, reduce risk, and ensure long-term sustainability.

The three primary factors in this effort are efficient and careful water and soil management and use of a broader base of genetic resources. The development of agricultural methods that maintain fertility with locally grown inputs is also important. As Gary Nabhan discovered, O'odham families sought out places where moist, rich litter has accumulated beneath mesquite trees, dig up the top 2-3 feet, and take it to the farm fields. Mesquite trees were also a source of fertility for crops that were grown among them, they can fix 30-40 kg of atmospheric nitrogen per hectare per year with only 30% canopy cover and the soil beneath them is often very fertile. Nitrogen fixation may take place at 5-8 meters depth and these deep roots can provide little competition for shallow-rooted crop plants grown nearby. Mesquite intercrops are common in India.

The floodwaters in these desert ecosystems often carry large amounts of rodent dung, leaves from nitrogen fixing trees, litter, and twigs. Enough material may come to floodwater irrigated fields in these floods to add an inch of organic matter a year.

Alternatives to the basic grains that are better suited for small farmers in lands with limited or uncertain water availability must also be considered. The special genetic adaptations of grains, beans, and corn developed by the farmers over hundreds of years will also be of great value for international development.

These techniques are proven and in combination could enable the inhabitants of many of the drylands of the world to achieve much better yields. Developing a program to help these skilled flood-water farmers to assist less experienced dryland dwellers in other areas deserves special attention. Refining these strategies for different soils, rainfall regimes, and crops is an important task which has received little attention.

The stream channel protection plantings in northern Sonora also deserve much wider recognition. The local farmers plant cuttings of cottonwoods and willows in long lines at the river edges of their fields. These living fences are then completed by weaving thorny branches between the trunks. The tree roots protect the fields from erosion and the fence helps reduce flow across the fields so floodwaters deposit their rich silt on the field.

F. Super-efficient irrigation

Specialty crops or "survival insurance" crops can be grown with supplemental water from deep pipe irrigation or unglazed pitchers set in the ground. Both offer maximum water efficiency with relatively simple operation. Experiments with buried clay pot irrigation have shown that crops can be produced with an effective water use around 20 mm/ha.

<u>a. Deep pipe irrigation</u>

Deep pipe irrigation is commonly done with 1" to 3" diameter pipe (bamboo, hollowed out sunflower stem, or ...) placed 12-18" (or deeper) into the soil under or near the crop plant or tree. Several pipes are used for a full grown tree. These may be filled with water bottles placed in the pipe (observed in Kenya), filled with water from jug, or fitted with a drip emitter.

Deep pipe irrigation is better than surface or buried drip systems in several respects. First, it can be used with low quality water and low technology. Second, even in areas where the materials and technology for drip systems are available the deep pipe system provides the benefits of buried drip, greater water use efficiency (due to reduced evaporation) and weed control; but these surface mounted deep delivery drip systems can be monitored and repaired much more easily. And, finally, the pipes can be collected at the end of the season for tillage operations to any depth desired.

Experiments in Africa and the California desert have showed that deep pipe irrigation is much more efficient than surface drip or conventional surface irrigation. Grape vine weight on the deep pipe drip system five times greater than conventional surface irrigation and more than double standard drip irrigation. Roots reached 100 cm horizontally with conventional surface irrigation, only 60 cm with surface drip, and 175 cm with deep pipe drip irrigation. Deep pipe drip develops a much larger effective rooting volume and would produce a plant much better adapted to survive on its own after establishment.

Deep pipe irrigation has provided excellent performance in the Colorado Desert. Survival of trees was 80% compared to total failure of surface irrigated trees given the same amount of water. Growth was almost as good as buried clay pot irrigation and the response of the deep pipe plants was better after a desert rain.

b. Buried clay pot irrigation

The buried clay pot method is one of the most efficient systems of irrigation known. Buried clay pot irrigation uses a buried, unglazed clay pot filled with water to provide controlled irrigation to plants near it. These can either be filled by hand if labor is inexpensive or connected to a pipe network or reservoir.

Earthenware pots are usually porous and work well. If red clay nursery pots are used the drain hole in the bottom should be plugged with a stopper or sealed with silicone caulk. The water seeps out through the clay wall at a rate that is influenced by the plant's water use. This leads to very high efficiency--considerably better than drip irrigation and as much as ten times more efficient than conventional surface irrigation.

The book Fan Sheng-chih Shu describes the use of buried clay pot irrigation in China more than 2,000 years ago. Current practices remain much the same.

Make 530 pits per hectare (210 pits per acre), each pit 70 cm (24 inches) across and 12 cm (5 inches) deep. To each pit add 18 kilograms (38 lbs) of manure. Mix the manure well with an equal amount of earth.

Bury an earthen jar of 6 liters (1.5 gallons) capacity in the center of the pit. Let its mouth be level with the ground. Fill the jar with water. Plant 4 melon seeds around the jar. Cover the jar with a tile. Always fill jar to the brink if the water level falls.

Buried clay pot irrigation has been used for a wide range of annual and perennial plants including: melons, tomatoes, corn, onions, and many other annual crops in China, Pakistan, India, Mexico, and Brazil; pistachio trees in Iran, mesquite, acacia, and eucalyptus in Pakistan, fruit trees in India and Mexico, citrus in Brazil, and palo verde in the California desert. It has worked well for most crops in our trials in Mexico, Arizona, and California. Some spreading squash and melons have not done well if the pots were overwatered.

The spacing of the clay pots depends on the crop and size of the pot. In general they will be 6-10 feet apart for vine crops and 3-4 feet apart for corn and other plants that grow up more than out. Buried clay pots are better than high technology drip systems in several respects. First, they are not as sensitive to clogging as drip emitters, although they may clog over time (3-4 seasons) and require renewal by reheating the pots.

Second, buried clay pots can be used without pressurized water systems. Third, the clay pots can be made with locally available materials and skills. Fourth, buried clay pots are less likely to be damaged by animals or clogged by insects than drip systems. And finally, while even a brief interruption of water supply to a drip irrigation system due to a pump or filter failure can lead to serious problems and costly damage to crops the buried clay pot systems may require water only once a week. This can be very important for small farmers who may have to travel away from home for work and for women who are busy with other family duties, such as water carrying (often 4-5 miles per day) and fuel collection.

By limiting water delivery to the area where the crop is grown the buried clay pots also reduce weed growth. This reduces competition with weeds for sunlight and nutrients and can increase crop yield. Fertilizer placement can also be more precise, limited weed growth.

This method would be used more widely if more farmers and foresters knew about it. Buried clay pot irrigation should be considered wherever water conservation is important. It will probably continue to prove most valuable for producing high value crops in dry lands. Buried clay pot irrigation is also valuable for food production and revegetation of areas affected by salinity or where only saline water is available for irrigation.

G. Dew, Frost, and Fog Precipitators

Water can also be collected with specially designed dew, frost, and fog precipitators. Dew and frost may form more than 200 nights a year in cool deserts where it rarely rains, as a result of excellent night sky cooling. Some plants and animals use this moisture naturally.

The farmers of the Wiltshire Downs in England have relied on dew ponds to help water their livestock for hundreds of years. These dew ponds also capture rainfall. Dew in the desert is likely to be a minor but valuable addition to the drinking water supply. With special precipitators using shielded high emissivity plates and special coatings, higher water yield could be generated and funneled to storage for drinking water.

Fog is also common in some deserts and fog drip may exceed rainfall beneath trees. Fog collectors have been used to collect water for many years in the coastal deserts of South America. Using modern materials and scientific understanding of the principles involved should make fog collectors much more efficient. Once trees are established they may "water" themselves.

H. Snow Traps

Snow fences and snow traps can be used to concentrate snow in dry lands to provide added water for crop growth. This is increasingly being used to improve establishment of windbreaks in semi-arid areas. Design recommendations and studies would help farmers build these traps with locally available material.

3. Food

One of the biggest failures of the American agricultural research system, and by its domination, the world research system, has been a narrow focus on a very few crops and their commercial production in intensive monocultural systems with costly inputs of energy, fertilizer, biocides, and water. Very little research has been undertaken to evaluate the hundreds of other food crops once considered staples by the indigenous people of the U.S. (and the world) and on the design of complex, sustainable systems for food production.

The small family farmer who must rely on limited resources (perhaps 1-3 ha of fields and 10-30 ha of catchment area) seeks moderate yield and minimum risk rather than maximum yield with high risk. A complex mix of drought adapted perennial and annual crops offers this mix.

The goal of a subsistence farmer would include the use of 50-150 species in an intercrop/multicrop system. Perennial crops would receive particular attention. These long lived plants can develop deep roots that utilize deep soil moisture and/or groundwater. Living mesquite roots have been found 85 meters deep. These large root systems can enable perennial plants to produce crops in seasons where annual crops would fail completely. A mix of trees, shrubs, and smaller plants should be utilized. Drought tolerant native species should be favored with only a small selection of crops that require supplemental irrigation or microclimate modification. (See Appendix A.)

The current food system produces only one calorie of energy for every ten calories invested, while traditional agricultural systems may return ten calories for every one invested.

B. Wild gathering

Wild gathering is still common in many areas of the U.S. and northern Mexico. While the overall contribution of calories may not be high the nutritional importance may be significant. As a good friend from Mexico has observed, "There are no weeds". Most of the common garden weeds, such as amaranth, orache, etc. are excellent greens and are widely used. A television program on these traditional "quelites" in the Valley of Mexico legitimized their use and led them to show up blister packed in up-scale grocery stores.

Education in schools and workshops could increase use of common edible wild foods. Emphasis should be placed on sustainable harvesting. No one need go hungry in many areas during much of the year.

C. Confined livestock, poultry, etc.

Overgrazing has been a major cause of deterioration of arid lands and as a result no free-grazing animals are proposed for the subsistence farm. Turkeys, quail, doves, chickens, rabbits, and perhaps guinea pigs, lizards, and rats, would be included. Highly drought adapted species such as the Kangaroo rat (*Dipodomys*), chuckwalla (*Sauromalus obesus)*, and Gambel's quail (*Lophortyx gambeli*) that can gain weight on a diet of dry food with no supplemental water should be used in the very arid regions of the Southwestern U.S. Comparable local species can be found in other areas of the world. Bees would be kept in areas with sufficient nectar.

Confined livestock could be added as vegetation recovers. A pig is often the first choice (except in Muslim communities). Confined cattle, pygmy goats, sheep, and dry land adapted cattle could also be considered. Conservation and evaluation of traditional breeds is important.

After range condition are restored sufficiently supervised grazing might be allowed for goats, peccaries (*Pecari angulatus)*, sheep, or cattle. Free grazing deer, antelope, or bighorn sheep (*Ovis canadensii*) would be preferable in the Southwestern U.S.. These desert adapted natives will usually produce more pounds of meat per acre than introduced species. Other areas might rely on camels and other drought adapted species.

Nomadic lifestyles are often sustainable and should be given greater credence in international planning programs. Many water well development and settlement programs have exacerbated environmental damage by concentrating livestock and also damaged very sophisticated nomadic cultural systems.

4. The Self-reliant Homestead

"... ere long the most valuable of all arts will be the art of deriving a comfortable subsistence from the smallest area of soil. No community whose every member posses this art can ever be the victim of oppression in any of its forms."

Abraham Lincoln

A. Water

Readily available clean water and hot water contribute to health and comfort. Roof surfaces, are usually the most inexpensive collectors. Gutters or ground troughs can be used to collect water. If roof areas are insufficient then threshing grounds, work areas, and other hard surfaces can be used to augment collection. Rainwater collection should be run through a filter system to house cisterns. Both a utility water and drinking water tank are desirable.

These storage tanks are often made of ferrocement or cement on a basket frame and should have sufficient capacity to meet minimal domestic demand through most of one dry season (or preferably two). For a family of four a 2,000 gallon tank would suffice but 5,000 gallons would be better. The determination of tank size and tank construction are detailed in Pacey and Cullis. Set underground or in an insulated shed (straw bales) they would provide cool water for the hot summer.

Cistern water could be augmented with nearby surface water in the rainy season or a well. Floodwater cisterns, known as a "harables" to the Bedouin, could be used to supplement water supplies. These floodwater cisterns were dug into solid rock above the floor of arroyos. Thus, the bed load of rocks and gravel does not fill up the storage space.

Small dams, including check dams made with rock filled gabions, can also help save runoff water. Water from a temporary pond can be pumped into a protected cistern. Water storage in arid areas can also be in "sand tanks" where water is stored in the pore space of sand and gravel. This reduces evaporation from the storage area.

Water treatment can include simple filtration with an upflow filter (made with sand, gravel and charcoal) or a ceramic filter. Further treatment can be provided by solar disinfection, exposing water to sunlight in a clear bottle for the uv radiation to kill viruses and other pathogens. If water is salty or dirty a solar distillation unit can be made with simple concrete and glass or plastic.

An integral solar water heater of rudimentary design can preheat water for cleaning clothes and bathing. If available, metal drums are good heater tanks (if free of pesticide petroleum, or biocide residue). Alternatively, a reduction fired (black) ceramic pot or pots can be used, set in a small insulated enclosure with glass or plastic cover.

Use of a mist shower system can reduce water demand for personal cleanliness and health from gallons to quarts and can be built for very low cost.

B. Food storage

Dehydration is usually the most practical method for storing food in arid regions. Virtually all of the foods collected and grown by indigenous desert dwellers have been dried successfully with no special equipment. With a solar dryer better results can be achieved with lower losses (and less contamination).

Corn, beans, mesquite pods, and similar staples can be kept for years if dried carefully and stored in pest proof containers. A series of ferrocement or large pots can be used for primary storage. With an airtight seal pest losses can be virtually eliminated.

The use of pickling, fermenting, and brining can also be advantageous. Cactus pears, cholla buds, and greens such as orache that are very seasonal could be stored in this manner, like Korean *kimchee* or European *sauerkraut*. A variety of chile salsas, preserves, and chutneys made from fruits would also help enliven and enrich the basic diet of seeds, nuts, beans, corn, acorns, and pods (mesquite and locust).

In some areas the use of *yahk chal* would be of value. This ancient Persian design maximizes night sky cooling to make ice (or chill water). With some tinkering and modern materials a *yahk chal* might provide sufficient ice for cold storage in an ice house through much if not all of the summer in temperate drylands.

C. Shelter

With water and food settlement becomes feasible, either seasonal or permanent.

<u>a. Construction</u>

The foundation of a comfortable life for a farm family is an energy efficient home made of local, affordable and biodegradable materials. Progress in energy efficient building design has been made in the last few years and homes are now regularly built in extremely cold climates that are livable throughout the winter using only body heat, internal gains (cookstove, etc.), and solar energy (south-facing windows). With very little supplemental heating these homes are very comfortable indeed.

Homes are also being built that provide summer comfort using climate resources to provide natural cooling in some of the hottest deserts. Yet the cost of these homes, while comparable to conventional construction, is far too expensive for many residents in the U.S. and Canada and way beyond the means of most people in the world.

Many of these people already live in homes using traditional designs that maximize passive solar heating and cooling by appropriate window placement and use of thermal mass, but the lack of insulation makes them barely tolerable to live in during cold periods even with high consumption of costly and environmentally destructive fuels (wood, straw, dung, etc.). During the summer the lack of insulation and sophisticated but simple natural cooling systems also makes them barely livable. These unreinforced adobe, brick, or stone buildings are also extremely hazardous in earthquakes.

A traditional building system developed in America and Canada can resolve this problem and provide well insulated, inexpensive, and earthquake resistant buildings for people around the world. Plastered straw bale buildings have proven inexpensive, durable comfortable and super-energy efficient. Buildings more than 70 years old are still in excellent condition. Rye, flax and rice straw were especially favored, but wheat, rice, oats, and barley, Russian thistle, *Salsoa kali*, and other weeds have also been used. Tall wheatgrass *Agropyron elongatum* is an excellent candidate for straw bales in arid areas becuae it will grow well in alkaline soil and the grain is good to eat.

Many of the early buildings were built with bales made with horse powered balers. Balers have also been designed for operation with just human power. This brings bale building within range of many dryland dwellers.

The insulation value of the straw bales depends on a number of factors including the density of the pack, moisture content, and type of fiber, but will typically be in the range of R 1.5 to 2 per inch. This makes it easy to achieve the high wall insulation values of R-30+ needed for super-efficient buildings. With proper window and building orientation, use of thermal mass (water, rock, or earth), and full use of natural heating and cooling strategies very effective and comfortable homes can be built at very low cost.

Straw bales are easy to use (stack and pin) and their width spreads the wall weight over a large area so smaller footings are needed. Straw bale walls can support the roof structure without additional beams or posts so minimal wood is required. A well-pinned bale building should be very stable and safe in earthquakes.

Current practice (more and more straw bale structures are now being built) is to use stucco or plaster inside and out over wire fencing or mesh, but fiber reinforced stucco or natural reinforcing materials such as woven bamboo lattice or fiber netting may prove equally useful. Asphalt stabilized adobe has been very effective and is low cost.

Roofing can be any material but would most logically be metal, ferro-cement, or tile for water collection and fire protection with attic insulation R-40+. Skillfully made thatched roofs can be made rodent proof and will last 40-100 years (even in damp climates). Traditional flat roof construction with straw insulation can also be used.

Development work is urgently needed on minimal cost straw bale building using low cost materials for stucco reinforcing; refining foundation design development and testing; roofing; system development and design of hand balers for areas too poor to afford the services of a motorized baler.

In areas where straw is unavailable, wattle and daub, clay/straw, reinforced adobe, or rammed earth may be used. With proper design, safe and reasonably comfortable buildings can be constructed using these materials.

In areas of extreme heat, people may continue to sleep outside on a roof or deck. When water is available, a small sheet metal roofed sleeping porch with water trickled on the roof can provide needed cooling by evaporation and night sky cooling. These were called submarines in the California desert.

D. Energy

The energy supply and demand of a self-reliant farm will vary considerably depending on climate, foods, cropping systems, and culture. Energy requirements should be reduced as much as possible by good design and met with renewable sources of energy -- sun, wind, wood (from a well managed woodlot), etc.

a. Solar

Using only simple materials, the major energy demand for home heating and cooling can be met with passive solar/climatically adapted design. Passive solar systems can also heat or preheat water for domestic use at very low cost. Preheating cooking water to 66^{o}+C (150^{o}+F) with a simple solar heater can reduce fuel requirements considerably. Solar box cookers are inexpensive and effective in areas with intense sunlight and clear skies. Further fuel savings can be made using well designed mud stoves or cookers made of broken bricks and chicken wire or metal from five gallon cans. The use of internal flue pots for water heating can save an additional 10-20%. Straw box cookers, which conserve heat from a pot that has been raised to cooking temperature on the stove or in a solar cooker, can further reduce heating requirements.

b. Wood

Very good design and rudimentary materials can dramatically lower energy demand for heating as much as 90% in colder climates. This will allow the remaining demand to be met by a small woodlot rather than by consumption of virtually all of the available dung, straw, and other crop residue produced on the farm and surrounding areas. This woodlot should be composed of a mix of trees, with preference given to nitrogen-fixing edible crop trees such as Mesquite *Prosopis*, Acacia *Acacia*, and Locust *Robinia*.

With a sustained yield of one ton/ha/yr, a typical farm would benefit from 1/2 ha of coppiced woodlot. The leaves can be collected for compost (or fodder with appropriate species selection) when the branches are cut for fuel. These trees can be intercropped with grains and vegetable to improved crop microclimate and maintain soil fertility.

c. Wind

Wind power can be harnessed for water pumping and grain milling. The sail wing wind machines are typically the most practical and economical machines to build and have proven themselves in many areas. When deep wells are to be pumped, more sophisticated designs must be used.

Very simple wind machines have also been used for mechanical power to run tools, mills, and processing equipment in the drylands.

d. Electricity

Electricity will remain a luxury beyond the reach of most inhabitants of the drylands. Photovoltaic cells and low voltage (12V) systems of very low output will usually be most economical for the home. These can provide lights, limited water pumping and refrigeration, entertainment, education (radio or TV), and communication.

E. Waste

A waste is a resource that has not been discovered.

a. Biological wastes

The Chinese and Japanese farmers of the not too distant past properly valued human and animal wastes. Nutrients were so valuable that the streets were swept after horses passed to collect the manure. No vegetable matter was wasted either, being fed to the animals, composted, or added to the fields. Oak leaves and other green manures were gathered from afar to improve field tilth and fertility.

The use of a solar ventilated composting privy is commonly the preferred solution for the disposal of human waste. A two pit design allows long composting periods for both safety and convenience. Finished compost can be used on tree crops. A water trap (using one quart per flush) may be used if fly problems occur.

Alternatively, a simple pit privy may suffice. This should be located down hill (and down wind) from the house. Natural plants for toilet paper can be developed.

Even chamber pots and the like can be successfully used with care in placement and disposal of wastes.

b. Non-biological wastes

A subsistence community will commonly have few other wastes to deal with. Metals, glass, and most plastic items are reused or can be recycled. (See wastes under community.)

5. The self-reliant community

For a sense of community and social interaction, dwellings should be clustered in the most protected and comfortable microclimates. However, for ready access to the fields (for the prerequisite storm water management) travel time must be kept to a minimum. In the industrial-technological era it was commonplace to make divisions between different disciplines such as agriculture, housing, and waste disposal. However, to create sustainable systems it is essential to integrate different disciplines and cultural practices which are specifically adapted to the ecosystem in which they are placed.

Many potential benefits exist from the cooperative integration of diverse disciplines and practices:

--Intensive gardening can be utilized also for climate control in residential areas through shading.
--Treated sewage effluent can be used to irrigate tree crops and can be biologically cleaned in managed wetlands.
--Sunspaces can be used for controlled environments to propagate and grow plants, as well as for heat collection for use in buildings.
--Community refrigerator waste heat can be used to heat water or dry food.
--Integral solar water heaters can be used to maintain stable temperatures for photovoltaic cells.
--Living fences can provide control of livestock, protect gardens, provide habitat for beneficial insects, and supply food for people.

The ability to take what may have been a pollutant in one process and turn it into a resource for another process is another benefit of integration. Developing these relationships often allows one process to accomplish what might have taken two or three before. Individual responsibility is increased when the user is intimately connected to the very processes on which life depends.

Design of the community facilities should maximize interaction with nature and between people. This design principle will make it easier for harmonious relationships to become embedded in daily life. The design of the buildings and houses will be done in a way which allows their integration into a complete sustainable system. Form and beauty are factors which need to be considered in relationship to energy, water, food, and community.

Materials should be chosen from the immediate bioregion. Every opportunity should be taken to utilize the design and practices of traditional cultures that have developed over hundreds of years from the interaction of intelligent, hard-working people with these difficult environments. Villages for service support (schools, blacksmith, potters, masons, doctor, dentist) should incorporate the same energy and water saving features as dwellings.

Another important aspect of integration is that which comes from transferring sustainable practices and technologies into daily living patterns. Modern society is often characterized by a very specialized and fragmented lifestyle which leaves the average person disconnected from the structures and functions that support life. These include nature in general, food production, and the supply of energy and water, and waste disposal.

A. Neighborhood economy

The last twenty years have seen a dramatic improvement in the understanding and application of climatically adapted, energy efficient building design. Unfortunately, subdivision and town planners have not embraced these new design methodologies and continue to neglect the many energy and environmental issues that are involved in development. While many planners are now exposed to these issues in college the basic outline of development is commonly laid down by the civil engineers who develop street grids and utility connections to minimize first cost. This is unfortunate because the neighborhood scale offers great potential for saving money and resources through energy conservation and renewable energy systems, recycling and multiple use.

While the educational system may justly be criticized for the lack of ecological literacy and the skills required for sustainable development in graduating engineers, architects, landscape architects, and business majors, the real problem is the difference between economics as the accountants and business people know it, and economics as the ecologist views it.

The gulf between these two world views is perhaps most easily demonstrated by their different treatment of present and future value and cost. The businessman for example, with a planning horizon of six months to a year, will emphasize the present with a high discount rate, while the ecologist, with a planning horizon of 100 years or more, would put a much higher value on the future and use a very low discount rate. Cost to the business person is often confined to production cost and sales price, while the ecologist would use, a larger, but often difficult to calculate, total cost including what are now externalized costs of environmental damage, the opportunity cost of options denied by spending, and the risk of future impacts of current actions.

This difference in accounting is the result of a deliberate but hardly conspiratorial effort by politicians to provide *seemingly* cheap food, energy, water, and housing. The mechanisms used to manipulate prices include a variety of government policies, primarily tax and investment related, which obscure the actual costs and transfer direct and indirect costs from the buyer to other individuals, groups, Society at large, and future generations.

These subsidies have not been well studied, but are enormous. The annual subsidy for non-renewable fuels, for example was estimated at more than 44 billion dollars for 1984, not including environmental costs. If these subsidies were removed and environmental costs and risks were added, energy prices would certainly be double, and more probably triple or quadruple what they are today. This would have a dramatic impact on the type of home and neighborhood consumers want and developers provide.

Progress toward energy self-reliant neighborhoods will be slow until the market more accurately reflects costs and benefits. Hopefully, the rising Federal deficit signals the incipient end of the enormous investment in collective stupidity characterized by our current planning and development activities. Even a country once as wealthy as the United States cannot afford this enormous waste. Current policies produce houses and neighborhoods that are not particularly comfortable, enjoyable, healthful, or durable, barely affordable, and certainly not sustainable. They provide no model or guidance for other less developed countries and regions.

C. Water

The water system for a community would include rainwater harvesting, neighborhood cisterns, and considerable recycling. While current water consumption in the U.S. is about 500 liters per day (v/s 160 in the United Kingdom), the Minimum Cost Housing Group and others have demonstrated that use could be cut to 10 liters per day with full conservation and reuse. The neighborhood scale is most appropriate for water systems, allowing investment in more elaborate storage and treatment facilities.

Community scale water supply projects should be built to use impervious surfaces within the village as collectors. These public systems would complement individual houses cisterns. Many lessons can be learned from the Nabatean settlements. Much can also be learned from Gibraltar, Bermuda, and Australian towns that rely on roof water collection and rainwater catchments for much of their water supply.

D. Food

Many residents would maintain their own gardens (America's 34 million home gardeners currently produce about 9 billion dollars worth of vegetables a year) others, who may be traveling away to cash "jobs" could have them worked by relatives or a share cropping system.

The kitchen gardens of many areas of the world suggest what can be done. These gardens, rarely operated as a primary occupation, provide a very high percentage of vitamins and minerals, and often a substantial portion of calories and cash income as well. Residential developments would establish farm areas for intensive production of basic commodities and biofuels. Landscaping for the neighborhood would be chosen for food, fodder, and biofuels, just as they currently are in the highly evolved garden/forest systems of the world.

E. Energy

The neighborhood scale offers several advantages for designers. Microclimates could be manipulated to improve summer cooling and winter heating and to improve livability of outdoor community space. Wood for heating would be collected locally, as a by-product of local woodlots, orchards and community landscape operations. Composting would be integrated with the neighborhood farm and landscaping.

Photovoltaics are often competitive with conventional power if subsidies are removed and would be used to meet primary electrical demand in most remote areas. Power demand could be kept to less than 1% of current demand by skilled design and efficiencies of neighborhood scale. The larger scale of development planning would reduce the per unit cost of more advanced systems, such as district total energy systems (which could also provide super-efficient freezer storage space--and laundry facilities), fuel cells, and wind energy or solar pond facilities. Neighborhood energy systems could be interlinked for resilience and backup.

A community electrical system is usually more practical than a house scale system. A readily available auto engine can be used to build a total energy system for community energy. If waste heat from this engine is used for district hot water heating (or a community laundry) high net efficiency can be achieved. A community freezer for storage of meats and other perishables might also be worthwhile. Waste heat from the freezer could also be used for water heating.

The design of neighborhoods and communities to a large extent determines transportation requirements and preferences. The City of Davis, with more than 30,000 bicycles and 15,000 daily riders, and Village Homes, with pedestrian and bicycle circulation emphasized and autos inconvenienced offers clear proof that it can be done, and is enjoyable. It is also very economical as Davis residents save more than 20¢ per mile by biking rather than driving and city residents save more than a million dollars a year by riding bicycles, money that stays in the community and stimulates local businesses.

Pedestrians are even more at the mercy of the developer and city planner. If proper attention is paid to microclimate, ease of access, safety, and convenience walking will be facilitated. For poor communities, walking can be enhanced by providing convenient access, summer shade, and drinking water.

E. Waste

Waste management is troubled by the same mis-economics as energy policy and neighborhood planning. First costs and current costs are narrowly calculated without full consideration of environmental costs and secondary impacts. In addition the waste "monopoly" of local government ties consumers into an expensive and inefficient system for treating waste. Stand alone or neighborhood systems would usually be much less costly than regional plants, but there is at present no mechanism for developers to use to develop these systems.

The most effective management of wastes is source control. This would be an integral part of an energy self-reliant community. Waste streams must be minimized and kept clean of hazardous materials so they can be biologically recycled. This would require a dramatic shift in marketing but a very small change in lifestyle. Household wastes would be composted or treated in ecologically engineered aquatic systems.

6. The Challenge Ahead

The drylands of the world are now suffering serious and in many cases virtually irreversible damage from human activities and grazing. With better design and a stronger commitment to sustainable development these lands could be restored to ecological health and would provide a much better living for their inhabitants. The longer we wait the harder and more expensive it will be as the resource bases continue to decline:

The restoration of the drylands and relief for the dryland dwellers will not occur unless this vital work is given the recognition and funding it requires. Natural scientists (botanists, ecologists, soil scientists, hydrographers, foresters, and range specialists), engineers, anthropologists, archeologists, planners and designers with the ability to see the human scale must learn from and work with these dry land dwellers to develop and refine sustainable agriculture systems. Failure to do this will be catastrophic for both people and the environment.

A. Education

One of the most important facets of education for sustainable management of dry lands is the recognition of and support for farmer to farmer interchanges. Often no one knows more about low-input practices than highly skilled farmers. Programs that recognize this are still rare. Interchange programs with small farmers also enable farmers to share biological resources. Often in the past, researchers ignored these farmers, but it has become clear that they are often much better at managing their limited resources and teaching their peers than researchers or extension workers. Much more support is needed for these programs to facilitate local, regional, and international exchanges and education programs.

The interaction of farmers with researchers and extension workers must also be a key part of a new educational program. In the past most of the interaction has been from the "educated" to the "ignorant" farmer, but it is often more appropriate for the knowledge of the farmer to be transferred to the researcher and extension worker. This will require more work to encourage researchers to listen and work with small farmers, who are often illiterate and timid in large meetings.

Ecological principles and sustainable land management should be an integral element of training for the general population as well. This can be done by developing appropriate curricula for schools and colleges. Gardening and restoration could be included in curriculums from kindergarten to college. Restructuring local, state and national policies to encourage conservation is also needed. The establishment of Conservation and Restoration Corps would be very helpful in providing training in the methods of sustainable resource management, research, and restoration.

One of the most important and currently neglected areas is the development of an accurate understanding of the condition and trends in land use and condition. The establishment of a National Ecological Survey with status and funding comparable to the

Geological Survey in the United States would be appropriate to undertake baseline monitoring and restoration studies. Much of the work should be done with long-term contracts on a ten-year cycle on a competitive grants basis.

The redirection of agricultural research at the university and college level could be accomplished by changing program emphasis and funding availability. Sustainability and restoration should be the cornerstones of this program. The foundation for this would be long-term sustainability and self-reliance and economic efficiency in the most conservative sense. Much of this research is low cost, but it takes many years and is not well-suited for the fast-paced publish or perish imperatives of the current academic setting. What is needed are long-term (10-20 year) grants with a recognition of the value of field research and practical application. Israel, for example, rewards practical application of research as highly as basic research.

B. Demonstration

Demonstration projects are critically needed in both developed and developing nations. We learn by doing, and demonstrations are critical to learn techniques and learn problems and solutions to complex problems. These can be on college campuses, research stations, wildlife parks and recreation areas and on private or NGO property. If people see that it works it will spread.

C. Restoration

The foundation of an economical and successful restoration program is first and foremost a clear understanding of the environment and the plants, animals, and people involved. A restoration program should begin with a study of the history of the land, its native vegetation (and human influences), the soil characteristics of comparable undisturbed native soils, and as much information as possible on the dominant plants and animals. When this information a draft plan for restoration can be developed.

The second step should be a series of test plots and demonstrations to evaluate the strategies for restoration that appear most promising environmentally and culturally. This is particularly important in areas where little information is available. While the test plots are underway a seed-collection program should be initiated, and seed nurseries should be established to increase seed stocks.

The essential elements of a miminum cost restoration effort are the introduction of appropriate seeds and related symbionts to microsites that provide suitable soil and moisture conditions for rapid root growth and plant establishment. This usually includes preparation of the soil by ripping, use of a garden fork, or chiseling; seeding with a complex mix of species inoculated with appropriate symbionts. Weed control can help slow growing native plants to compete. Controlled burning at the time weed species are most vulnerable or soil solarization can provide weed control without chemicals.

Other low-cost techniques that have been successful include the use of pitting discs and imprinting. When very little money is available, the best option is simply to roughen up the soil surface. A rough surface increases infiltration and traps blowing soil and seeds. More expensive treatments will provide more rapid revegetation. These treatment might include ridging, catchment basins, mulch, and pest control. Mulching and composting can also provide many benefits. Native grasses with seed are excellent for mulching if they are available; but straw is also of value. High application rates with crimping to retain the straw are desirable, particularly on erosive slopes. Compost is also of value, when it is available.

Other restoration program elements that may be of value include pest control (cages or fencing to protect plants), rodent control, limited irrigation, and fertilizer. Fertilizer should be used with care because it may increase shoot rather than root growth, increase weed competition, depress microsymbiont development, and make plants more palatable for pests.

Transplants are expensive but they may make it possible to establish plants that are not easily started from seed in the field. Containers and nursery management should develop a root system (with symbionts) suited for survival in a difficult environment. Deep containers may provide substantial benefits in this regard. Transplants will usually require cages or screens to reduce grazing pressure from insects, rodents, livestock and deer.

Timing of transplanting can be critical for establishment. Transplanting in the desert may be feasible only after a flood event. 95% survival has been obtained by doing this in the Negev Desert. Even transplants that die may provide some cover and increase establishment of seedlings.

It may be desirable to combine expensive treatments, i.e. transplants, on a very limited area (1-2%) with strip treatments, i.e. pitting and direct seeding, on a larger area (perhaps 10-20%). This approach can establish seed sources for subsequent natural revegetation of the remaining land. Revegetation of 10% of the land in a project area in

Eastern Oregon had a very positive effect on the remaining 90% by reducing grazing pressure and providing a new seed source.

There is no excuse for waiting any longer. The drylands are waiting for long overdue attention. *A journey of a thousand miles begins with a single step.*

Appendix A: Partial Plant List for the Southwestern U.S. and Northwestern Mexico.

The following species would be logical candidates for a self-reliant dry farm. Special preference would be given to those that produce food and can fix nitrogen. These are indicated with an asterisk. Some of the more promising species are indicated with an E. Several seed suppliers can be found, although some very promising species are not in the trade regularly.

Plants for Food

TREES

*Prosopis glandulosa**	Mesquite		E
*Prosopis velutina**	Mesquite		
*Prosopis pubescens**	Screwbean Mesquite		
Cercidium floridum	Palo verde		
*Olneya tesota**	Ironwood		
Pithecellobium flexicaule	Texas Ebony		E
Acacia spp. esp.,	Acacia		
Acacia greggii	Catclaw acacia		
Acacia farnesiana	Sweet acacia		
*Robinia neomexicana**	Locust		
*Gleditsia triacanthos**	Honey locust		
Quercus spp. - esp.	Oaks	Acorns	
Q. gambelli	Gambel oak	sweet	
Q. emoryii	Emory oak	sweet	
Q. oblongifolia	Mexican oak	sweet	E
Q. kelloggii	Black oak	oily	E
Q. macrocarpa	Bur oak	sweet	E
Pinus spp. - esp.	pines		
P. edulis	Pinyon pine		
P. sabiniana	Grey (ex. Digger) pine		
P. coulteri	Coulter pine		
Juniperus spp.	Junipers		
Juglans spp.	Walnut		
Corylus cornuta	Hazelnut		
Prunus fremontii	Desert apricot		

Yucca brevifolia	Joshua Tree
Pistacia spp.	Pistachio
Palmae spp.	Palms

With supplemental water for flood runoff, microcatchment basins, buried clay pots, or drip irrigation from cistern or well, and perhaps with microclimatic modification: Apricot (3-4 varieties), Fig, Quince, Carob, Jujube, Locquat, Hickory, Almonds, Pecans, Citrus (3-4 var.), Apple (low chill req. in warm desert), date (3-4 var.), etc.

<u>SHRUBS</u>

Opuntia spp.	Cactus	veg, fruit	E
*Shephardia argenta**	Buffalo berry	berry	E
Yucca spp.	Yucca, esp.		
Yucca baccata	Banana yucca	veg, fruit, seed	E
Agave deserti	Agave	veg, fruit	
A. utahensis	Agave	veg, fruit	
Ribies spp.	Currants	berry	E
Amelanchier spp.	Serviceberry	berry	E
Rosa spp.	Rose	hips	
R. strigosus	Raspberries	berry	
Vaccinium spp.	Gooseberry, etc.	berry	
Viburnum spp.	Mooseberry, etc.	berry	
Rhus spp. esp.			
Rhus trilobata	Lemonade sumac	berry	
Sambucus spp.	Elderberry	berry	
Vitis spp.	Wild grapes	berry	
Prunus spp. esp.			
P. americana	Wild plum	fruit	E
P. virginiana	Chokeberry	fruit	
Physalis spp.	Ground cherry	fruit	E
Lycium pallidum	Wolfberry	berry	E
Heteromeles arbutifolia	Toyon	fruits	
Berberis spp. esp.			

Berberis repens	Creeping Barberry	berry
Simmondsia chinensis	Jojoba	nut/oil
Atriplex lentiformis	Quailbush	shoots/seeds

LEAFY VEGETABLES AND POTHERBS

Montia perfoliata	Miner's lettuce	
Atriplex patula	Orache	E
Urticum spp.	Nettle	
Chenopodium spp.	Lambs quarters	E
Rumex spp.	Dock	
Stellarium spp.	Chickweed	
Portulaca spp.	Purslane	E
Brassica spp.	Mustard	
Taraxacum spp.	Dandelion	
Cleome	Beeweed	
Monolepis spp. esp.		
M. nuttaliana	Poverty weed	

Cultivated species: Beets, kale, asparagus, chard, parsley, nasturtium.

ROOTS, TUBERS, ETC.

Psoralea esculenta	Breadroot	E
Orogenia linearifolia	Indian potato	
Lewisia spp.	Bitteroot	
Alliums spp.	Wild onions	
Oenothera spp.	Evening primrose	
Perideridia gairdneri	Yampa root	E
Calochortus spp.	Sego lily, etc.	
Cymopterus purpurascens	Biscuit root	
Lillium spp.	Lily	
Ammobroma Sonorae	Sand food	

Where standing water exists:

Typha latifolia	Cattail	E

Damp areas:

Potentilla anserina	Silverweed
Sagittaria lattifolia	Wapatoo

CULTIVATED VEGETABLES

E - Tepary bean[1] *Phaseolus acutifolius,* pinto bean, squash, carrots, corn, esp. Hopi corn,[2] peas, peppers, radishes (daikons), potatoes, salsify, garlic, onion, carrots, turnips, jicama, jerusalem artichoke, Armenian cukes, etc.

[1]The tepary bean produced quadruple the amount of modern beans in one test under dryland conditions.

[2] Hopi corn is an excellent example of the type of improvement that can be made by selection and breeding. This corn has an elongated mesocotyl (2-3 times modern corn) and a deep thrusting radicle rather than seminal roots. The kernels are planted 2-3" deep at the bottom of a deep holes (6-10"). As the corn grows the hole is filled in, placing the roots 12" deep where more soil moisture is available. A dust, rock or sand mulch is used to reduce evaporation. Hills are spaced widely (9' x 9') and yield is about 600 lbs/acre.

SEEDS AND GRAINS

Atriplex patula (tolerates salinity/ alkalinity)	Orache	E
Chenopodium spp.	Lambsquarters	E
Amaranthus spp.	Amaranth, Pigweed, etc.	E
Oryzopsis hymenoides	Indian ricegrass	E
Panicum spp.	Panic grass	
Healianthus spp.	Sunflowers	E
Rumex spp.	Dock	
Atriplex caenescens	Fourwing saltbush	E
Lepidium sp.	Peppergrass	

Agropyron spp. esp.	Wheatgrass	E
A. elongatum	Tall Wheatgrass	
Cleome spp.	Beeweed	
Sporobulus spp.	Sand dropseed	E
Salvia spp. esp.		
Salvia columbariae	Chia	E
Salvia reflexa	Rocky Mtn. sage	
Salvia mellifera	Black sage	E
Salvia apiana	White sage	
Yucca spp. esp.		
Y. glauca	Spanish bayonet	

Cultivated species: millet, wheat, rye, buckwheat, barley, sesame, teff, sorghum.

<u>SPECIAL CROPS</u>

Q. ilex	Cork oak	insulation

<u>Hedges & Fences</u>

Opuntia	cactus
Crataegus spp.	Hawthorne
Prosopis	mesquite
Acacia gregii	catclaw
Fouquieria splendens	ocotillo

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(bold highlights key books and papers)

Desertification is often used inappropriately, land degradation or deterioration is more accurate in most cases.

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