DRYLAND FARMING: CROPS & TECHNIQUES FOR ARID REGIONS

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INTRODUCTION

In every region of the world it is necessary to find or develop appropriate techniques for agriculture. A large part of the surface of the world is arid, characterized as too dry for conventional rain fed agriculture. Yet, millions of people live in such regions, and if current trends in population increase continue, there will soon be millions more. These people must eat, and the wisest course for them is to produce their own food. Yet, the techniques are so varied that only a very large volume would cover the entire subject. This publication is only a primer, an introduction to appropriate techniques. More extensive treatments are mentioned in the bibliography. In many cases the most suitable techniques for a particular region may be those already developed by the local inhabitants. In some cases it will be difficult to improve on local techniques, but at times even simple and inexpensive innovations may be almost revolutionary. This technical note suggests that one must begin to improve local agriculture in arid zones by learning what is already there. Then both techniques and plants that may be useful in specific situations are suggested.

Definitions and Degrees of Aridity

Arid implies prolonged dryness, and is used with respect to the climate itself, and the land below it. In such regions the ability to produce agricultural crops is restricted. Usually on arid lands the potential evaporation of water from the land exceeds the rainfall. The land may be characterized according to the degree of aridity as dry forest, chaparral or brushland, grassland or savannah, or desert. The word, "arid" does not adequately characterize the soils, however, for they may vary in many ways. Often they are alkaline or saline.

Several degrees of dryness must be recognized. The first is where the dry climate is modified by seasonal rainy seasons. In such a region it might be possible to produce a wide range of annual crops during the short rainy season, enough to sustain animals and feed mankind, although few food or feed trees might be feasible without special techniques.

The second situation is a year round aridity, sometimes modified by light or irregular rains, which might make production of crops impossible.

The third situation is where water is brought in by wells, canals, or other means so that normal agriculture can exist, in spite of the aridity of the climate. This primer concerns the first two situations, but not the third. There are techniques suitable for all arid regions.

PRINCIPAL ARID REGIONS OF THE WORLD

The arid regions of the world are often very extensive, but in the tropics it is common, even on a small island, to find arid regions not far from regions of abundant rainfall. Some of the larger arid regions are:

North America
- Much of Western USA
- The Sonora Desert

Central America
- The Pacific Coast

South America
- The Atacama Desert
- The Serrano of Brazil

Australia
- The Central Deserts

Africa
- The Sahara Desert
- The Sahel
- The Kalahari Desert
- East Africa

Asia
- The Middle East
- The Indian or Thar Desert
- The Namub Desert
- The Karakum Desert
- The Gobi Desert

However, while the above mentioned regions may constitute the most arid regions, nevertheless, there are many more areas, large and small, where aridity is a problem.

PRINCIPLE PROBLEMS OF AGRICULTURE IN ARID REGIONS

Water

Water is absolutely necessary for all plant and animal life. Plants have evolved that are capable of living and reproducing in semi arid, arid, and even desert regions. However, as aridity increases, fewer and fewer species are adapted, and the potential biomass is reduced.

Plants are adapted to aridity by several mechanisms. There are plants with a short life cycle that can germinate, grow, and produce during a very short period of available moisture. There are plants with deep or extensive root systems which have the ability to gather water over a wide area. There are plants which store up water in their tissues and release it very slowly. There are plants that are protected from water loss by wax or other impediments. There are plants with very small or narrow leaves, thus reducing water loss. There are plants in which the tissues themselves can withstand much desiccation without dying. Crop plants in arid regions may have any or a combination of such mechanisms.

Water that falls in arid regions may be of little use for crop plants because the amount is too small to penetrate the soil sufficiently, or it may run through a porous soil too quickly, or it may run off too quickly. Furthermore, weedy species may be so adept at utilizing scarce water that they rob the water from crops. On the other hand, some soils can store water so efficiently that is possible to grow crops in such soils over an extensive period of drought.

Water from rivers, lakes and wells in arid regions may have problems of quality, especially the presence of excess minerals. The use of irrigation water might lead to the accumulation of salts in the soil resulting in alkalinity or salinity, which might then limit crop production. The removal of salt from the soil is very difficult.

In all arid regions a major challenge is to manage water appropriately. The purpose of such management is to obtain water, to conserve it, to use it efficiently, and to avoid damage to the soil.

Heat and Wind

The major effects of heat and wind are to increase the rate of evaporation of water, and thus to increase the effects of aridity. Wind may also cause mechanical damage to crops. Both are combated by changing the microclimate. The effects of winds can be reduced by windbreaks (lines of trees perpendicular to the direction of prevailing winds). Some useful tall species are tamarisk, casuarina, and eucalyptus. A windbreak can consist of trees and other plants of varying height. As a general rule, a windbreak is effective over an area two and a half times the height of the tree. One must remember, however, that a windbreak may also rob crops of light, water and nutrients. Thus, the advantages of a windbreak must be weighed against the disadvantages in any particular environment. Windbreaks can also be constructed of non-living materials, which are likely to be expensive.

Heat is received principally from the sun and can be reduced by shading. But, shading also reduces the yields of plants. A light shade such as that below a coconut planting or a protective screen or lathwork can be useful in reducing heat and retaining moisture, with only a minimum loss of yield.

Soils

Soils of the arid tropics are highly variable, as they are in any climate. Nevertheless, it is possible to make some generalizations about such soils. Because of the low rainfall and consequently reduced plant growth, organic material is produced slowly. Yet, again because of low rainfall, it may be broken down slowly as well. The amount of organic material in the soil, and thus the potential fertility, is likely to be high in semi-arid zones, low in deserts.

Because of low rainfall in desert soils minerals derived from breakdown of rocks are not leached from the soil. In some cases where the soil is periodically flooded or irrigated the soil might be saline as well. Such soils support few crops.

Soils of the semi-arid and arid zones might support few plants on the surface, but a good part of the biomass might be in the soil itself as roots. Shrubby desert plants often have very hard woody roots that may be a physical barrier to agriculture.

Disease and Pest Problems

Arid regions have their fair share of disease and pest problems. However, these may often be quite different from those of wetter regions. Nematodes are often a severe problem in sandy soils. No general rules are useful, and indeed, agriculture anticipates diseases and pests, and their parasites as well.

CROPS & LIVESTOCK FOR TROPICAL ARID REGIONS

FOOD & NON-FOOD PLANTS

Crop plants for arid regions are those that survive and produce in spite of aridity. However, in almost all of these crops, seeds must be germinated or cuttings must be rooted under conditions of almost normal water availability. Therefore, when one speaks of tolerance of dry conditions one is talking mostly about the drought tolerance of the growing or mature plant. In the following tables food and feed crops as well as crops of other uses, and other plants that are useful in arid regions are considered. These plants vary in ability to tolerate aridity and in yields under arid conditions. Choosing the right crops for arid regions might involve considerable experimentation in a particular region, and, in fact, the development of suitable production systems might require years. This should come as no surprise. Native systems, as crude as they may appear, usually represent the accumulated wisdom of centuries of experimentation. If this is so, how can one hope to make an improvement? The answer is often in the introduction of species or varieties unknown in the region in question. In other cases it is related to the introduction of new technology developed in other regions. Fortunately, such new technology is now available (see literature).

Table 1. FOOD PLANTS FOR DRY REGIONS OF THE TROPICS.

Scientific Name	Common Name	Degree Of Tolerance*
CEREAL GRAINS		
Zea mays	Corn	1.0
Sorghum bicolor	Sorghum	1.5
Pennesitum americanum	Pearl Millet	2.5
GRAIN LEGUMES		
Phaseolus vulgaris	Common Bean	1
Vigna unguiculata	Cowpea	1.5
Cajanus cajan	Pigeon Pea	2.0
Dolichos lablab	Lablab Bean	2.5
Vigna radiata	Mung Bean	2
Phaseolus acutifolius	Tepary Bean	2.5
Vigna aconitifolius	Mat Bean	2.5
Tylosema esculentum	Marama Bean	3
LEAFY VEGETABLES		
Symphytum officinale	Comfrey	1
Manihot esculenta	Cassava	1
Cnidoscolus chayamansa	Chaya	2
Moringa oleifera	Horseradish Tree	2
Leucaena leucocephala	Leucaena	2.5
ROOT CROPS		
Dioscorea rotundata	White Yam	1
Manihot esculenta	Cassava	2.0
Sphenostylis stenocarpa	African Yam Bean	2
FRUIT VEGETABLES		
Citrullus lanatus	Watermelon	1
Cucurbita mixta	Mixta Squash	1.5
Abelmoschus esculentus	Okra	1.5
MISCELLANEOUS VEGETABLES		
Cynara scolymus	Globe Artichoke	1

Table 1. FOOD PLANTS FOR DRY REGIONS OF THE TROPICS, continued.

Scientific Name	Common Name	Degree Of Tolerance*

FRUIT TREES		
Carica papaya	Papaya	1
Pouteria campechiana	Canistel	1
Psidium guyava	Guava	1
Spondias cytherea	Golden Apple	1
Olea europaea	Olive	1.5
Tamarindus indica	Tamarind	1.5
Zizyphus jujuba	Jujube	1.5
Carissa carandus	Karanda	2
Dovyalis abyssinica	Dove Plum	2
Punica granatum	Pomegranite	2
Anacardium occidentale	Cashew	2.5
Opuntia sps.	Prickly Pear	2.5
Phoenix dactylifera	Date	3
OIL PLANTS		
Pentaclethra macrophylla	Owala Oil	1
Helianthus annuus	Sunflower	1
Butyrospermum paradoxum	Shea Butter	2
MISCELLANEOUS		
Catha edulis	Khat	2

Rated from 0 (no tolerance) to 3 (high tolerance)

Table 2. **NON-FOOD PLANTS FOR ARID REGIONS.**

Scientific Name	Common Name	Degree of Tolerance*
FEED LEGUMES		
Gliricidia sepium	Mother of Cacao	1
Ceratonia siliqua	St. John's Bread	1.5
Prosopsis sps.	Mesquite	2.0
Leucaena leucacephala	Leucaena	2.0
Acacia albida	Apple Ring Acacia	2.5
Acacia tortilis	Umbrella thorn	2.5
Parkinsonia aculeata	Jerusalem Thorn	3.0
FEED GRASSES		
Cynodon dactylon	Bermuda Grass	1
Digitaria decumbens	Pangola Grass	1
Sorghum sudanense	Sudan	1
FIBER PLANTS		
Gossypium barbadense	Sea Island Cotton	1
Agave fourcroydes	Henequen	2
Agave sisalana	Sisal	2.5
TIMBER PLANTS		
Swietenia mahogoni	Mahogany	1
Acacia tortilis	Umbrella Thorn	2.5
PLANTS FOR ALLEY CROPPING		
Gliricidium sepium	Madre de Cacao	1
Cajanus cajan	Pigeon Pea	1
Leucaena leucacephala	Leucaene	1.5

Table 2. **NON-FOOD PLANTS FOR ARID REGIONS,** continued.		
Scientific Name	Common Name	Degree of Tolerance*
GROUND COVER		
Dolichos lablab	Lablab Bean	2
Canavalia ensiformis	Jack Bean	1
WINDBREAK		
Casuarina spp.	Casuarina	2
Eucalyptus spp.	Eucalyptus	1.5
Tamarisk spp.	Tamarisk	2.5
LIVING FENCE		
Gliricidia sepium	Mother of Cacao	1.5
Bursera simaruba	Gumbolimbo	1.5
Acacia nylotica	Babul Acacia	2.5
Euphorbia tirucali	Pencil Euphorbia	3

Rated from 0 (no tolerance) to 3 (high tolerance)

ANIMALS FOR DRY REGIONS OF THE TROPICS

In dry regions of the tropics where agriculture is always difficult, animals are frequently more capable of utilizing the often abundant plants that are available, and often can be fed with crop residues. While some feed crops are given in Table 2, the most important feeds in many regions will be those which grow by themselves, naturally and untended. Sometimes improvement of this natural fodder by fertilizing, watering, or selected weeding may be the best solution to increasing the yield of animal feed. In addition, as elsewhere, appropriate care of animals is necessary, and even very poor herdsmen are often skilled in raising animals.

Animals on the farm can be used for a wide variety of purposes. In addition to excellent food in the form of eggs, milk and meat, animals serve as beasts of burden, and can be trained to handle difficult jobs on the farm. The dung is a useful resource for crop production but is also used in plastering walls and floors, and when dry, as fuel. Animal wool, hair, or fur can be used in bedding and clothing.

Principal Animals and their Characteristics

Cattle. In many arid regions the production of cattle might be the best way to make use of land. Cattle feed principally on grasses, but also benefit from legumes. They are much less apt to graze or brouse on shrubs than goats. They are very adept at finding something useful to eat on grasslands, even during the dry season. Cattle may be used for milk, for meat, for farm labor, and for their hides and other by-products. There are many breeds of cattle, often used for a single purpose, or at times serving for two or more principal purposes, and some of these will be much more adapted to a given situation than others. Choosing the appropriate breed or strain of cattle will always be important.

The carrying capacity of land, the number of cattle (or, other animals that can be raised on it), will vary widely, and can determine the success or failure of a given venture. Cattle may graze in open range or fenced pastures, but in either case, rotation is necessary in order to not destroy the future potential of the grazing area. Improvement of the grazing area can be achieved by the introduction of new grasses or legumes, by fertilization, occasionally by fire (a risky process), by killing poisonous plants, and by eliminating brush and some trees. Some breeds will gain more on a given pasture than others.

Since cattle raising is a capital intensive effort (for, even the cattle represent considerable capital), a great deal of investigation and local knowledge is desirable before embarking on such an enterprise. On the other hand, raising the family cow is possible almost everywhere and can be the foundation of success on the small farm.

Goats. Goats, because of their size, are often called the poor man's cow, and may be produced for about the same purposes as cattle. Goats are often grazed on open range in arid regions. They are browsers (nibble at many kinds of plants), and sometimes are better adapted to production of useful meat than are cattle, especially in heavy shrubland. While goats may be raised for milk, the really fine milk varieties are seldom well adapted in the tropics.

Sheep. In addition to the wool-bearing sheep of the temperate zone, there exist hairy sheep much better adapted to the tropics. In addition to their value in producing meat, such sheep are often used to control weeds in orchards, and thus constitute a profit producing biological control.

Burros. The small donkey of the drylands of the world is supremely adapted to living off the browse and meager feed often available, and for its size is surprisingly strong and a magnificent beast of burden. Not to be laughed at, the burro can easily be adapted to useful roles on the farm, including basic transportation and pulling carts.

Camels. This species is best adapted to very dry areas where agriculture is very limited.

The choice of animals for the farm in the arid tropics, and the techniques used to raise such animals are very important, and vary considerably from one region to another.

Feed Crops

No element in the production of animals is more important than feed, unless, of course, it is adaptation. Farmers in a given region may be quite conscious of acceptable treatments in care and breeding of their animals. They may not be aware of the progress that could be made by improvement of feeds, even though such advice may be available through local agricultural experiment stations, extension services, or the department of agriculture. A first step in improving animal production should be to learn how farmers are feeding animals, and the second step is to learn what feeding practices are recommended. A third possible step, much more difficult, is to learn the feeding practices of areas of similar soils and climates.

Dry season feeds. A major problem in the production of animals is what to feed them during the dry season. An efficient production system includes working out and solving this problem in advance. Some of the potential solutions include: dry season irrigation of pastures; restricted grazing of pastures during wet seasons, so that feed will remain for the dry season; harvest and storage of wet feed as silage; harvest and storage of dry feed as hay, or as seed, in the case of grain crops; and migration to more productive areas.

One of the most useful possibilities for increasing amount of dry season feed is the use of crop residues. The value of such residues as feed varies, and sometimes other substances are added to enhance palatability or nutritive value. In a well-managed agricultural enterprise of any kind, it will be useful to look for such potential used of residues.

Still a further solution to the problem of dry season feed shortage is to reduce the size of the herd as the dry season approaches. The frequent practice of letting animals go hungry cannot be recommended as good husbandry.

Dryland Farming techniques
Dry Farming is the profitable production of crops, without irrigation, of land with a low average or highly variable rainfall.

- Farm practices must conserve and utilize the available rainfall to the fullest extent. To obtain maximum storage of moisture under any rainfall condition, the soil must absorb as much water as possible when it rains and losses by evaporation or transpiration must be kept to a minimum.
- Quick maturing, drought resistant crops must be grown.
- Rainfall must be greater than 10 inches per year (250 mm).
- Wind and heat must not cause excessive evaporation at critical stages of plant growth.
- Soil should be deep (preferably 10 feet - 3 meters) with no clay, sand, or gravel seams to interfere with capillary movement of water. The minimum feasible soil depth is 18 inches (450 mm) but water storage capability and drought resistance increases with increasing soil depth.

Dryland Farming Techniques

Increase Water Absorption

Prevent a Crust at the Soil Surface. Probably the greatest deterrent to a high rate of water absorption is the tendency for soils to puddle at the surface and form a seal or crust against water intake. The beating action of raindrops tends to break down clods and disperse the soil.

- By tillage, create a rough, cloddy surface which lengthens the time necessary for the rain to break down the clods and seal the surface. For seed bed preparation in general, small seeds should have a finer, mellower bed than large seeds.
- After harvest, create a stubble mulch on the surface. Such material not only prevents raindrops from impinging directly on the soil, but impedes the flow of water down the slope, increasing absorption time.

Reduce the Runoff of Water. To the extent that waterlogging is not a problem, the runoff of water and its attendant erosion must be stopped.

- Cropland should be as level as possible.
- All tillage and plantings must run across (or perpendicular to) the slope of the land. Such ridges will impede the downward movement of water.
- For every two feet of vertical drop or 250 feet of horizontal run, the field should either have bunds or contour strips (details of these practices are discussed later).

Reducing the Loss of Soil Moisture

Reducing Soil Evaporation. Water in the soil exists as a continuous film surrounding each grain. As water near the surface evaporates, water is drawn up from below to replace it, thinning the film. When it becomes too thin for plant roots to absorb, wilting occurs.

- Shelter belts of trees or shrubs reduce wind speeds and cast shadows which can reduce evaporation 10 to 30 percent by itself and also reduce wind erosion.
- Mulching reduces the surface speeds of wind and reduces soil temperatures.
- Shallow tilling can create a dirt mulch 2 to 3 inches deep which dries out easily but is discontinuous from the subsurface water, preventing further loss. Tillage must be repeated after each rain to restore the discontinuity. This is most workable where rainfall occurs in a few major rainfalls with relatively long intervals in between.

Reducing Transpiration. All growing plants extract water form the soil and evaporate it from their leaves and stems in a process known as transpiration.

- Weeds compete not only for soil nutrients, but water as well and so their control is critical.
- Selection of crop is significant as well. Dwarf varieties have less surface and so lose less water. Some plants close their stomas when it is hot, reducing their water loss. Others, like corn, curl their leaves during hot afternoon and open them at night, effectively changing their surface area in response to conditions.
- In dry farming, the number and spacing of plants is reduced so that fewer plants compete for soil moisture. The exception to this occurs when allowances for insect, bird, and rodent loss must be made at planting.
- Where rainfall is frequently marginal to insufficient, drought "insurance" can be obtained by clear fallowing a sufficient area. An area clear of growing vegetation with a properly maintained stubble and soil mulch can retain 20 to 70 percent of the precipitation received until the next year. Where 5 to 6 acres each year per family have been so set aside in India, the specter of famine due to drought has been eliminated.
- Post harvest tillage will create stubble and dirt mulches and destroy weeds before the onset of the dry season.

Dry Farming Practices

Dry farming builds upon a knowledge of general agriculture but carries out its practices in the light of the significant probability that this year or next will be a drought. The following agriculture practices are discussed with this background.

Bunding. The first essential step in dry farming is bunding. The land is surveyed and level contours determined every hundred feet. For unusual slopes, it is recommended that for every fall of two feet, a bund 18 to 24 inches in height be constructed. Even when land is fairly flat, a 12 inch high bund every 250 feet is still found useful. Excess storm water is released by constructing periodic waste weirs with a sill of one-half bund height. This will retain water and minimize the loss of topsoil.

In order to make the bunds, land must be marked by the surveyor with bund lines. A few feet on either side of it, the land should be plowed and harrowed. The bund former should be worked along the bund twice, side by side, leaving a furrow in between. This furrow in the middle should be filled in with soil from the plowed portions on both sides, by means of a scraper. The outlets or "waste weirs" should be constructed of stones.

The natural drainage of the area must not be completely stopped but should be controlled by providing suitable outlets for excess storm water to pass gradually, without carrying much silt with it, and after fully saturating the soil and subsoil. The major natural drains in each village area or watershed must be properly maintained so that all fields have some outlet for the extra storm water.

Strip Cropping. Strip cropping is a technique that serves to control erosion and increase water absorption thereby maintaining soil fertility and plant response. In effect, it employs several good farming practices such as crop rotation, contour cultivation, stubble mulching, etc. By growing in alternating strips crops that permit erosion and exposure of soil and crops that inhibit these actions, several functions are performed:

- Slope length is maintained.
- Movement of runoff water is checked.
- Runoff water is desilted.
- Absorption of rainwater by soil is increased.
- Dense foliage of the erosion resisting crop prevents rain from beating directly on the soil surface.

Strips are, of course, planted perpendicular to either the slope of the land or the prevailing wind direction, according to whether water or wind presents the more serious erosion potential. Additionally, crops which do not resist erosion should be rotated with crops which do. Research has shown that:

- A normal seed rate of groundnut (peanut) is an efficient and suitable crop for checking erosion.
- The normal seed rate of leguminous crops other than groundnut does not provide sufficiently dense canopy to prevent raindrops from beating the soil surface; is should be raised to three times the normal seed rate.

- On the average, the most effective width of contour strips for cereals such as sorghum and millet is 72 feet and for the intervening legume, 24 feet. As slopes vary, so do the optimum strip widths, as shown below:

Table 3. **OPTIMUM STRIP WIDTHS.**

Slope	Width Of Erosion Permitting Crops	Width Of Erosion Resisting Crops
1% and below	150 feet	30 feet
1% to 2%	80 feet	20 feet
2% to 3%	45 feet	15 feet
3% to 5%	20 feet	10 feet
greater than 5%	10 feet	10 feet

Summer Fallow. All of the principles of water conservation and utilization pertaining to dry-farming will not make a crop grow if sufficient rain does not fall. Where the soil depth exceeds 18 inches (450 mm), however, it has been shown that it is possible to store water as soil moisture from one year to the next by the use of proper summer fallow techniques. With a soil depth of 10 to 15 feet, up to 75% of the incident water may be retained though 20% to 40% is more normal. Thus, in an area that averages sufficient rainfall for crop growth, it will be rare that the sum of the stored water and incident water will not be sufficient for crop production. Where families in India have faithfully set aside 5 to 6 acres for summer fallow each year, drought-induced famine has been virtually eliminated.

The partial loss of a crop in the year of fallow is offset to a great extent by a very much increased yield in the year of cropping. Such increased yield in a year of failure of the general crop in the surrounding areas, has a far greater value than a normal crop of a good season.

In order to accomplish this objective, the soil must be loose and permeable to soak up the rainfall and the dirt/stubble and mulch must be maintained to minimize evaporation. The land is worked with a tine-cultivator followed by occasional harrowing, particularly after rainfall, and weeds (which use as much or more water as crops) must not be allowed to grow. Though this expenditure on cultivation is relatively small, neglecting to provide the surface mulch at any time may cause more moisture to evaporate in a few, hot days than would fall during the whole season.

Experience has shown that where rainfall is 10 to 15 inches per year (250 to 375 mm/yr.) a clear fallow every other year is necessary and, at 15 to 20 inches per year (375 to 500 mm/yr.), every third year.

Mulches. Water easily enters porous soil and, as it seeps downward, becomes absorbed as films of water around the soil grains. These films form a continuous column of water to the surface of the soil. The film tends to remain the same thickness around all the soil grains with which it is in contact. This film of water in the soil is known as the capillary water and is the source of water for the plants.

The sun, wind, and dry air will cause evaporation at the surface, thus reducing the thickness of the film at the surface. The thicker films in the subsoil will rise to equalize the distribution again. This will continue until the films are so thin that the plant roots can draw no further moisture from them. The result is drought.

Stubble mulching aims at disrupting the soil drying process by protecting the soil surface at all times, either with a growing crop or with crop residues left on the surface during fallows. To be effective, at least one ton per hectare must cover the surface, and the maximum benefit per unit residue is obtained at about two tons per hectare. Benefit may still be obtained at 8 tons per hectare.

The first benefit of a stubble mulch is that wind speed is reduced at the surface by up to 99%, significantly reducing losses by evaporation. In addition, crop and weed residues can improve water penetration and decrease water runoff losses by a factor of 2 to 6 times and reduce wind and water erosion by factors of 4 to 8 relative to a bare fallow field. There are two limitations to the advantages of stubble mulch farming:

1. Dead surface vegetative matter can provide a home/breeding ground for plant diseases, insects or rodents. Use of a mulch not related to the succeeding crops will minimize much of the disease and insect effects. Use of stubble mulch only in the dry season will minimize all biological activity.
2. For decomposition, the ideal carbon to nitrogen ratio (C/N) is 25 to 30. Dry, woody, or non-green straw, stalks, etc. have a C/N of 50 to 100. This tends to slow decomposition and deplete soil nitrogen temporarily.

Nitrogen is a major requirement for protein synthesis by plants. A stubble mulch during a biologically active period such as the rainy season, should only be used when either:

- Soil nitrogen is very high.
- Plant nitrogen needs are very low (such as cassava).
- A nitrogen-containing fertilizer is used.

To obtain the benefit of mulching on soil structure without causing temporary de-nitrification, the mulch can be composted before adding it to the soil. Rapid bacterial action in the tropics makes composting less beneficial than in temperate climates but may still be worthwhile.

Dirt mulching aims at disrupting the soil drying process with tillage techniques that separate the upper layer of the soil from the lower layers, making the soil moisture film discontinuous. In addition the soil surface is made more receptive to water intake. Principles of dirt mulching:

- Effectiveness increases with increasing depth to a limit of to 4 inches (75 to 100 mm).
- Increasing the dirt mulch depth decreases the available fertile soil.
- The effectiveness of dirt mulches decrease with age. Consequently it must be recreated by shallow tillage of harrowing after each rain or each month (whichever is more frequent).
- The crumb form of dirt mulch (particles greater than 1 mm) is more effective and resists wind erosion more than the dust form.
- Dirt mulches can only be properly made when the soil is moist.
- For a climate with a "rainy" growing season and a hot, windy, dry season, dirt mulching should only be performed during the rainy season and with a growing crop to slow the wind and water and hold the soil.

The improper use of a dirt mulch presents serious erosion potential. The "dust bowl" condition in the great plains of the U.S. that destroyed or damaged millions of acres of prime cropland was a direct consequence of the abuse of the dirt mulch.

<u>Plowing / Tillage Practices</u>. Plowing, when the soil is in the proper condition, wears the soil into thin layers, and forces the layers past each other. If the soil is too wet when plowed (especially if it is heavy), the soil crumbs or granules are destroyed, thus puddling or compacting the soil. When the soil is too dry, the soil tends to pulverize and form dust. Plows with steep moldboards have the greatest pulverizing action upon the soil. The plow with the less steep moldboard has less tendency to puddle the soil and is of less draft.

- To produce a rough, cloddy surface that will increase moisture absorption and reduce runoff, as well as erosion from wind and water.
- To control/destroy weeds that compete with crop for sunlight, nutrients, and water.
- To destroy or prevent the formation of a hard pan (sole) which can develop after repeated shallow plowing or harrowing. This hard pan can stunt root growth, reduce water storage, and check the capillary rise of water from the subsoil.

- Promote bacterial activity by aerating soil, encouraging the decay of residues and the release of nutrients.

Timing of Tillage. Plowing, like planting, is sensitive to moisture and neither should be done when soil is either too wet or dry. In the arid and semiarid tropics, proper moisture conditions are likely to occur only at the beginning of the rainy season and should be done on the same day. If possible, planting should immediately following plowing, with seed rows centered on the furrow slices. A crosswise harrowing will cover seeds and close air spaces, thus creating a dirt mulch and keeping out the drying winds. If the crop is then harrowed/cultivated several times during the season, especially after rains, much moisture will be conserved.

The proper soil moisture condition for plowing is indicated by a manual soil test. The usual test is to squeeze a handful of soil. If it sticks together in a ball and does not readily crumble under slight pressure by the thumb and finger, it is too wet for plowing or working. If it does not stick in a ball, it is too dry. When examining soils, samples should be taken both at and a few inches below the surface. Soil that sticks to the plow or to other tools is usually too wet. A shiny, unbroken surface of the turned furrow is another indication of excessive soil moisture. In general, sandy soils and those containing high proportions of organic matter bear plowing and working at higher moisture contents than do heavy clay soils.

In semi-arid regions, the soil after harvest time is generally too dry for good plowing. Yet if the field is left uncultivated, this dry condition may become even worse and weeds will also grow and go to seed. The field should be harrowed (or plowed without moldboard) and crop residues left to form a stubble mulch to absorb/retain moisture and soil until the rains return.

Stubble should not be immediately covered and incorporated in the soil unless rodent or insect infestation is heavy (and even then burning should be considered). It has been well demonstrated that it is normally impossible to raise the soil organic matter content in areas where temperatures are high for long periods. When moisture is present, the rates of oxidation are extremely high and incorporated organic matter is lost quickly. The benefits thus derived from decomposition, as occurs in the more temperate regions, are not normally experienced. When left on the surface, however, organic matter does not decay so rapidly. Incorporation with the soils will tend to depress the levels of available nitrogen, to the detriment of crops if soil nitrogen is low. If soil nitrogen levels are adequate, the incorporation of residues to the soil may be beneficial if done with spring plowing at the start of the rainy season.

Depth of Plowing. Generally speaking, heavy clay soils should be plowed deeper than light, sandy soils, in order to promote circulation of the air and bacterial activity. Deep plowing on sandy soils, which are naturally porous and open, tends to disconnect the seed bed from the subsoil and speeds soil drying by too free a circulation of air in the soil.

In semi-arid climates, the greatest advantage to be gained from deep plowing (5-8 inches) is the development of a comparatively large moisture reservoir. When land is not plowed more than 3 or 4 inches deep for a period of years, a hard plow sole is very likely to form, through which roots and rain can only penetrate with difficulty. A shallow plow sole will saturate quickly with rainwater and increase runoff rates. As a rule, tillage below 5-6 inches also causes increased evaporation rates, losing precious water.

This deep plowing need not necessarily be done annually. Depending on soil and rainfall, a deep plowing of 5-6 inches every 2 to 5 years is satisfactory. As noted earlier, the soil mulch attains maximum effectiveness at a depth of 3-4 inches which can be maintained with a hand harrow/cultivator.

Deep plowing in some clay and loam soils will reduce yields for one or two seasons afterward as a result of an acidic subsoil. This may be dealt with by liming the soil (neutralizing the acidity) or by varying the depth of the plowing slowly so that the acidic subsoil is exposed a little at a time. This practice will also eliminate the plow sole.

Seed Bed Preparation. In general, smaller seeds require a finer, mellower seed bed than larger seeds. Seeds germinate and plants grow more readily on a reasonably fine, well prepared soil than on a coarse, lumpy one, and thorough preparation reduces the work of planting and caring for the crops. It is possible to overdo the preparation of soils. They should be brought to a granular rather than a powder-fine condition for planting.

Planting. Planting of crops should be in rows to permit inter-tillage as described later.
Planting Density. Limited moisture dictates the necessity for wider row spacing and lower rates of seeding (by one-half to two-thirds) than are used in moisture abundant areas. The resulting reduced plant population provides more moisture and nutrients per plant and thus enhances the possibility of the crop reaching maturity before the supplies are exhausted. Cereals should be planted 7 to 14 inches (18 to 35 cm) apart and crops such as millet, sorghum, sesame, safflower, etc. in rows 28 to 42 inches (70 to 105 cm) apart. In some cases, the practice of planting 2 or 4 rows and skipping one is successful in further increasing the efficiency of moisture utilization. In general, with limited rain, higher seed rates produce more straw/stubble at the expense of grain production.

Table 4. **AMOUNT AND DEPTH OF SEEDING FOR DRYLAND CROPS.**

Crops	Amount of Seed per Acre	Depth to Plant
Alfalfa, thickly sown	6 - 8 pounds	1 - 2 inches
Alfalfa, in rows	3 - 4 pounds	1 - 2 inches
Barley	1.25 – 1.5 bushels	3 - 4 inches
Brome grass, thickly sown	6 - 8 pounds	2 inches
Brome grass, in rows	3 - 4 pounds	2 inches
Corn	6 - 8 pounds	3 inches
Emmer or speltz	1.5 – 2 bushels	3 - 4 inches
Flax	0.25 – 0.5 bushel	1.5 - 2 inches
Millet, sown in rows	0.25 bushel	1.5 - 2 inches
Millet forage, thickly sown	0.25 – 0.5 bushel	1.5 - 2 inches
Oats	1.5 – 2 bushels	3 - 4 inches
Potatoes	8 - 10 bushels	4 - 5 inches
Rye, winter	3 - 4 pecks	3 - 4 inches
Sorghum or Kafir corn, in rows	3 - 6 pounds	1.5 - 2 inches
Sudan grass, in rows	4 - 6 pounds	1.5 - 2 inches
Sweet clover, thickly sown	10 - 12 pounds	1 - 2 inches
Sweet clover, in rows	4 - 6 pounds	1 - 2 inches
Vetch Dakota, thickly sown	0.5 bushel	2 - 3 inches
Wheat, winter	0.75 – 1 bushel	3 inches
Wheat, durum	0.75 – 1 bushel	3 inches

Intertillage / Cultivation. Crops sown in rows can take advantage of intertillage practices which serve three basic functions:

- Easy weeding without meticulous hand labor. Weeds compete for moisture and nutrients, thus they should be destroyed while small, before they have grown more than 2 or 3 leaves. If seeds are broadcast, or thickly sown, they can at best only be cultivated manually, a back-breaking task.
- Increase the formation of nitrates by bacteria. Cultivation aerates the soil and forms a mulch of dead weeds and stubble on which bacteria operate and form nitrates. Cultivation for this purpose should be undertaken during the early period of plant growth, and should be relatively deep, on the order of 2-3 inches.
- Intertillage conserves moisture by the formation of a dirt mulch as described earlier. It is imperative that cultivation be performed after rainfalls. Even a light rain can re-form capillary connections between the stored soil moisture and the surface of the ground. After a few drying days like that, it is possible for soil moisture to be lower than before the rainfall.

Crop Rotation. One of the first principles of dry farming with regard to cropping practices is that crop rotation as practiced in more humid regions is not necessarily recommended in semiarid lands. The following constitute the chief differences:

- Only a limited number of crops are adapted to the climatic conditions and the farmer must sow the crop best suited to the moisture conditions encountered at that time.
- Moisture is so dominantly limiting, that "soil improving" crops are much less effective than in more humid areas.
- Success with rigid or complex sequences is difficult in the face of widely varying rainfall.

Reasons For Crop Rotation. There are five basic reasons why crop rotation should be practiced:

1. Moisture Conservation. Any system of crop rotation should be planned with moisture requirements as the main consideration. For a given set of climatic conditions, a crop may be described as either moisture dissipating or conserving. After harvest of a moisture conserving crop, the soil contains more moisture than at planting. This reserve of moisture can help guarantee the succeeding crop. (see paper on Determining the Water Needs of Plants)

   Crops which are sown in rows so that intertillage and dirt mulching can be practiced tend to be moisture conserving. Under sowing may also assist in conservation.

   Moisture may be insufficient to both grow a crop and conserve enough water to ensure the succeeding crop. In such a case it is necessary to utilize the dirt and stubble mulched fallow in the rotation. If annual rainfall is 10 to 15 inches (250 to 375 mm) this will be needed at least every other year; if rainfall is 15 to 20 inches (375-500 mm) at least one in every three.

   In the West African sahel drought may be expected one year in four. Between 1968-1973 the rate was one year in two. In a situation like this, setting aside mulched fallow each year for moisture conservation will significantly aid survival. Where this has been faithfully practiced in similar areas in India, the specter of famine by drought has been virtually eliminated.

2. Pest Control. Where related crops are successively planted in the same place, viruses, molds, blights, and selective insect pests tend to build up in the soil. Crop rotation that leaves at least two years in between subject plants in the same location will eliminate the abnormal buildup of most such pests for most crops.

3. Erosion Control. Plants which are thickly planted or which produce a thick ground cover tend to resist erosion much better than those which are intertilled or tend to be moisture conserving. Loss of soil due to erosion is a significant dry farming problem and erosion controlling crops should be included in a rotation, preferably in a strip cropping mode.

4. d. Soil Nutrients and Structure. When related crops are successively planted, specific soil minerals and nutrients are withdrawn faster than they can be replaced by decay or subsoil movement. This selective depletion causes a soil to be "worn out" quickly. Simple rotation of crops makes depletion more uniform so that soils "wear out" more slowly.

   The planting of legumes (such as gram or groundnut or alfalfa) with their nitrogen fixing capabilities tends to restore soil fertility. The use of green manures (plowing under of a green crop, such as alfalfa, rather than harvesting) can also aid soil nutrients and texture but benefits may be short lived in the tropics and difficult for Third World farmers. The planting of any deep or thickly rooted plants (such as grasses, alfalfa, etc.) tends to improve soil structure and draw subsoil nutrients to the surface like a natural fallow and can increase pasturage during dry periods. Crops like cassava which require relatively little soil nutrients may also be grown for rotation or when soil is almost worn out.

5. Distribution of Labor and Risk. It is generally advisable for the subsistence farmer to grow all crops in the rotation scheme simultaneously, apportioning to each crop the fraction of fields that it requires. This helps the scheduling and distribution of labor at the bottlenecks (planting, harvesting, etc.) so that the entire crop need not be done simultaneously. There is also a reduced risk of total crop failure and increased variety/nutrition in the diet.

Crop and Variety Selection. Choice of varieties is important. Varieties which have proven excellent in irrigated or high rainfall areas are generally unsuited for dry land conditions. Many attempts at dry land farming have failed, largely due to lack of recognition of the requirements for the variety selection.

Variety requirements for dry farming:

- Short-stemmed varieties with limited leaf surface minimize transpiration.
- Deep, prolific root systems enhance moisture utilization.
- Quick-maturing varieties are important in order that the crop may develop prior to the hottest and driest part of the year and mature before moisture supplies are completely exhausted.

The Tables on the following pages list favorable conditions for various annual crops.

Table 5. **CROPS WITH TOLERANCE TO VARIOUS STRESSES.**

Characteristics	Crop Names
High temperature tolerance:	Cotton, Ground Nut, Chilies, (favor Jute & Yams only in humid tropics)
Drought resistance:	Common Millet, Barley, Chickpeas, Safflower (lower temperatures) Sorghum, Bullrush Millet, Phaseolus crops Radiatus (gram mung bean), Cassava, Castor Bean, Sesame, Ground Nut (Spanish variety), Pigeon peas, Sunflower
Lower temperatures favor:	Wheat, Potato, Sugar, Tomato, Safflower
Very high rainfall tolerance:	Rice, Cassava, Yam
Wide climatic tolerance:	Maize, Soybean, Ground Nut (Valencia & Virginia type), Phaseolus lunatis, Kenaf, Hemp, Sweet Potato, Sugar cane, Tobacco

Table 6. **GROWING SEASON AND RAINFALL REQUIREMENTS FOR SELECTED DROUGHT RESISTANT CROPS – CEREAL CROPS.**

Characteristics			Crop Name				
			Maize	Sorghum	Common Millet	Bullrush Millet	Barley
Number of Days	From sowing to 50% flowering	Early Maturing	50-65	50-65	35	35	70-80
		Late Maturing	65-90	65-90	60	60	80-90
	From sowing to harvest	Early Maturing	90-110	90-110	60	60	95-110
		Late Maturing	110-140	110-140	90	90	110-130
Rainfall after Sowing [1]	Early Maturing	(Sand) No moisture storage	400 mm/ 3 months	200 mm/ 2 months	125 mm/ 1 month	125 mm/ 1 month	225 mm/ 2 months
		(Clay) Maximum Moisture Storage	200 mm/ 3 months	100 mm/ 2 months	50 mm/ 1 month	50 mm/ 1 month	60 mm/ 2 months
	Late Maturing	(Sand) No Moisture Storage	500 mm/ 4 months	400 mm/ 3 months	200 mm/ 2 months	200 mm/ 2 months	350 mm/ 3 months
		(Clay) Maximum Moisture Storage	300 mm/ 4 months	200 mm/ 3 months	200 mm/ 2 months	100 mm/ 2 months	150 mm/ 3 months
Rainfall in Month of Flowering [2]	(Sand) No Moisture Storage		40 mm/ 10 days	30 mm/ 10 days	30 mm/ 10 days	30 mm/ 10 days	30 mm/ 10 days
	(Clay) Maximum Moisture Storage		25 mm/ 10 days	15 mm/ 10 days	15 mm/ 10 days	15 mm/ 10 days	15 mm/ 10 days
Rainfall at Harvest [3]			70 mm/ 10 days	50 mm/ 10 days	50 mm/ 10 days	50 mm/ 10 days	50 mm/ 10 days

(1) Rainfall after sowing equals the total rainfall accumulated after sowing for the indicated months. In general the rainfall requirements are slightly lower at higher altitudes than indicated. The potential evapotranspiration does not change much during the rainy seasons for tropics and subtropics. Sowing after a dry season starts at the moment that there has accumulated more than 60 mm in less than 30 days. The maximum moisture storage with a soil at field capacity is approximately 100-150 mm. When a crop is sown in an soil at field capacity much less rainfall is required during the growing season.

(2) Rainfall in the month of flowering is for the 30-day period from 20 days before 50% flowering to 10 days after 50% flowering.

(3) If the crop is to be harvested by combine, rainfall during harvest should be less than 120 mm/month (and much less than that if there is a heavy overcast and/or rains in the late morning).

Table 7. **GROWING SEASON AND RAINFALL REQUIREMENTS FOR SELECTED DROUGHT RESISTANT CROPS – LEGUMES.**

Characteristics			Crop Name			
			Ground Nut	Chickpeas	Pigeon Peas	Phaseolus radiatus
Number of Days	From sowing to 50% flowering	Early Maturing	60		100	50
		Late Maturing	90		210-300	80
	From sowing to harvest	Early Maturing	95-110	120	150-180	60-90
		Late Maturing	110-140	180	270-360	90-120
Rainfall after Sowing [1]	Early Maturing	(Sand) No moisture storage	300 mm/ 3 months	200-300 mm/ 3 months	500-1000 mm/ 6 months	350 mm/ 3 months
		(Clay) Maximum Moisture Storage	125 mm/ 3 months	0 mm/ 3 months	300 mm/ 6 months	125 mm/ 3 months
	Late Maturing	(Sand) No Moisture Storage	500 mm/ 4 months	300-400 mm/ month	700-1300 mm/ 12 months	450 mm/ 4 months
		(Clay) Maximum Moisture Storage	300 mm/ 4 months	100 mm/ 4 months	700-1300 mm/ 12 months	250 mm/ 4 months
Rainfall in Month of Flowering [2]	(Sand) No Moisture Storage		60 mm/ 10 days	25 mm/ 10 days	40 mm/ 10 days	
	(Clay) Maximum Moisture Storage		60 mm/ 10 days	25 mm/ 10 days	40 mm/ 10 days	
Rainfall at Harvest [3]			30 mm/ 10 days	25 mm/ month	50 mm/ month	50 mm/ 10 days

See endnotes at bottom of Table 4

Table 8. **GROWING SEASON AND RAINFALL REQUIREMENTS FOR SELECTED DROUGHT RESISTANT CROPS – OIL CROPS**

Characteristics			Crop Name			
			Safflower	Sunflower	Sesame	Castor Bean
Number of Days	From sowing to 50% flowering	Early Maturing	90			
		Late Maturing				
	From sowing to harvest	Early Maturing	120	70-110	40-70	100-150
		Late Maturing		110-150	100-140	150-180
Rainfall after Sowing [1]	Early Maturing	(Sand) No moisture storage	300-400 mm/ month	300-450 mm/ month	225-350 mm/ month	450-750 mm/ month
		(Clay) Maximum Moisture Storage	100 mm/ 4 months	100 mm/ 3 months	60 mm/ 2 months	250 mm/ 4 months
	Late Maturing	(Sand) No Moisture Storage		500-700 mm/ 4 months	500-700 mm/ 4 months	500-900 mm/ 6 months
		(Clay) Maximum Moisture Storage		300 mm/ 4 months	300 mm/ 4 months	300 mm/ 6 months
Rainfall in Month of Flowering [2]	(Sand) No Moisture Storage		30 mm/ 10 days			
	(Clay) Maximum Moisture Storage		30 mm/ 10 days			
Rainfall at Harvest [3]			25 mm/ 10 days	40 mm/ 10 days	40 mm/ 10 days	20 mm/ 10 days

See endnotes at bottom of Table 4

Table 9. **GROWING SEASON AND RAINFALL REQUIREMENTS FOR SELECTED DROUGHT RESISTANT CROPS – ROOT CROPS.**			
Characteristics			Crop Name Cassava
Number of Days	From sowing to 50% flowering	Early Maturing	
		Late Maturing	
	From sowing to harvest	Early Maturing	180-450
		Late Maturing	700
Rainfall after Sowing [1]	Early Maturing	(Sand) No moisture storage	900 mm/ 12 months 100 mm/ 6 driest months
		(Clay) Maximum Moisture Storage	
	Late Maturing	(Sand) No Moisture Storage	1500 mm/ 12 months 70 mm/ 2 driest months
		(Clay) Maximum Moisture Storage	
Rainfall in Month of Flowering [2]	(Sand) No Moisture Storage		
	(Clay) Maximum Moisture Storage		
Rainfall at Harvest [3]			40 mm/ 10 days

See endnotes at bottom of Table 4

Table 10. **TEMPERATURE REQUIREMENTS FOR SELECTED ANNUAL, DROUGHT RESISTANT CROPS.**

	Mean Monthly Temperature (Degrees C)			
	For Germination	For Growth	Minimum for Growth	Maximum for Growth
CEREAL CROPS				
Maize	10	15	Frostless	47
Sorghum	15	18	Frostless	45
Common Millet	5	--	--	55
Bullrush Millet	10	15	Frostless	55
Barley	5	23 @ 80% rh 30 @ 40% rh	--	50
LEGUMES				
Groundnut	18	20	Frostless	50
Phaseolus Radiatus	15	18	Frostless	40
Chickpea	5	12-22	15	--
Pigeon Pea	10	15-26	Frostless	--
OIL CROPS				
Safflower	5-17	17-32	5	43
Sunflower	10	18-27	--	43
Sesame	18	38	Frostless	--
Castor Bean	15	29	Frostless	40
ROOT CROPS				
Cassava	--	20-29	--	--

Table 11. **SOIL REQUIREMENTS FOR SELECTED DROUGHT RESISTANT CROPS.**

Soil Characteristics		Cereal Crops			Legumes			
		Maize	Sorghum	Millet	Ground Nut	Bean	Gram	Cowpea
Texture	Heavy		X				X	
	Medium	X	X	X	X	X	X	X
	Light		X	X	X	X		X
Minimum rooting depth (cm)	Deep (90+)							
	Med. (60-90)	X	X		X	X	X	X
	Shallow (30-60)			X				
Fertility	High	X						
	Medium		X	X	X	X	X	X
Salt Tolerance	Good							
	Moderate						X	
	Poor	X	X	X	X	X		X
pH Range		5.5-7.5	4.5-8.5	5.0-6.0	6.0-8.0	5.5-7.5	5.5-7.5	5.5-7.5
Tolerance to short periods of water logging		Low	Medium to High	Medium	Low	Medium to Low	Medium to Low	Medium to Low
Minimum depth of ground water during growth period (cm)		75	50	60	60	30-50	30-50	40

Table 9. SOIL REQUIREMENTS FOR SELECTED DROUGHT RESISTANT CROPS, (continued).

Soil Characteristics		Oil Crops				Root Crops
		Soybean	Safflower	Sesame	Sunflower	Cassava
Texture	Heavy					
	Med.	X	X	X	X	X
	Light	X	X	X	X	X
Minimum rooting depth (cm)	Deep (90+)					X
	Med. (60-90)	X	X	X	X	
	Shallow (30-60)					
Fertility	High		X	X		
	Med.	X			X	X
Salt Tolerance	Good					
	Moderate	X				
	Poor		X		X	X
pH Range		5.5-7.5	5.5-6.5	5.5-7.0	6.0-7.5	5.5-6.5
Tolerance to short periods of water logging		Medium	Medium to Low	Medium to Low	Medium	Low
Minimum depth of ground water during growth period (cm)		75	50			60

USEFUL PUBLICATIONS & RESOURCES

Prepared by Scott Sherman, ECHO

<u>Publications</u>.
Agroforestry in Dryland Africa by Rockeleau, D., Weber, F. and Field-Juma, A. 1988, ICRAF (International Centre for Research in Agroforestry, Nairobi, Kenya). 311 pp. cost: $31.00

Agroforestry in Arid and Semi-arid Zones by Shankarnarayan, R. A. (Ed.) 1984, ICAR (Central Arid Zone Research Institute, Jodphur, India), 295 pp.

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More Water for Arid Lands, Promising Technologies and Research Opportunities and *Saline Agriculture, Salt-Tolerant Plants for Developing Countries*, both by National Academy of Science (National Research Council, Office of International Affairs, 2101 Constitution Avenue, Washington, D.C. 20418), complementary copies available to development workers upon request. For review of the latter see *ECHO Development Notes* issue 35.

The Challenge of the Negev by Dr. Evenari (Ben-Gurion University of the Negev, P.O. Box 1025, Beer-Sheva 84110 ISRAEL)

Food from Dryland Gardens by David A. Cleveland and Daniela Soleri (Center for People, Food and Environment, 344 South Third Ave., Tucson, AZ 85701).

Practical Guide to Dryland Farming Series: *Introduction to Soil and Water Conservation Practices*; *Contour Farming with Living Barriers*; *Integrated Farm Management*; and *Planting Tree Crops* by World Neighbors in Indonesia (Studio Driya Media; Jl. Tubagus Ismail Raya No. 15; Bandung, West Java 40143; Indonesia) available from ECHO for $4 per book plus postage (Surface: $1.50. Air mail: the Americas - $3.00 for 1 book plus $1 each additional; Europe - $4.00 for 1, plus 1.50 each additional; elsewhere - $5.00 plus $2.00 each additional). For review see *ECHO Development Notes* issue 37.

<u>Seed Sources</u>.
Seeds of Change (621 Old Santa Fe Trail, #10, Santa Fe, NM 87501).

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Kimseed (attn. Stephen Hill, Australian Revegetation Corporation Ltd., 51 King Edward Road, Osborne Park 6017, Western Australia, Phone: (09) 446-4377).

<u>Information Sources</u>.
Desert Legume Program (2120 East Allen Road, Tucson, AZ 85719). Publish the quarterly bulletin *Aridus.*

Office of Arid Land Studies (The University of Arizona, 845 North Park Ave., Tucson, AZ 85719)

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Maricopa Agricultural Center (37860 W. Smith-Enke Rd., Maricopa, AZ 85239).

International Crops Research Institute for the Semi-Arid Tropics (Patancheru, P.O. Andhra, Pradesh 502-324, India)

International Center for Agricultural Research in the Dry Areas (P.O. Box 5466, Aleppo, Syria)

Drought Defenders Project (Henry Doubleday Research Association, Ryton-on-Dunsmore, Coventry, CV8 3LG, UK).

Arid Lands Information Network (174 Banbury Road, Oxford, OX2 7DZ, UK, texex:83610). Publish *Baobab*, a networking publication for those working in arid lands.

International Institute for Environment and Development (3 Endsleigh St., London, WC1H ODD, UK, phone 071-388-2117, fax 071-388-2826). Publish *HARAMATA, Bulletin of the Drylands*.

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SEPASAL (Survey of Economic Plants for Arid and Semiarid Lands, Centre for Economic Botany, Royal Botanic Gardens, Kew, Richmond, Surrey TW9 3AE, UK, fax +44.81.332.5278).

Video.
*Looking After our Land: Soil and Water Conservation in Dryland Africa***.** (Oxfam publications, PO Box 120, OX2 7DZ, U.K.). The 2 hour tape costs £13 and the illustrated 84 page book £6.95. When ordering specify whether you want the English or French version and whether your video equipment uses the PAL, SECAM or NTSC system (postage: 20% in the UK, 35% Far East and 25% elsewhere). For review see *ECHO Development Notes* issue 35.