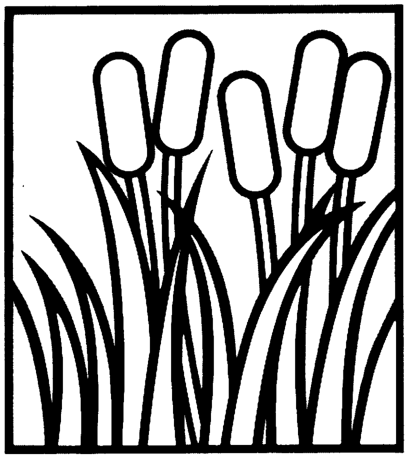

Selected Technologies Affecting Land and Water Management

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Chapter XI

Selected Technologies Affecting Water and Land Management

Continued agricultural productivity of arid and semiarid lands will require more careful and integrated management of many resources, including water. Improved water and land management can help to restore the inherent productivity of many agricultural lands that suffer from erosion, soil compaction, soil salinity, or other adverse conditions. In irrigated areas, better water management may compensate for the decreasing availability of affordable water which many experts predict,

Management technologies rely on brainpower and there is no substitute for intelligent use of technology and "smart" users when resources become less available. This chapter highlights an assortment of these lesser known, and sometimes unconventional, practices for managing water and land. This discussion is not all-inclusive, however. Rather, each technology has shown its usefulness i n some locations and may play an increasing role in arid and semiarid agriculture in the Western United States.

THE WATER SETTIN6

Most irrigation systems and arid/semiarid-land cropping systems developed to manage water; historically, patterns of agricultural land use and agricultural practices reflected this characteristic. Today, the more promising contemporary management schemes show a similar understanding of water in arid/semiarid lands: the limited absolute amounts of water, its spatial and temporal unevenness, its susceptibility to effectite exhaustion, and the interconnected nature of different water resources. As an example, some areas are using the watershed (the fundamental hydrologic unit) as a political management unit. In other locations, individuals recognize that it is difficult to affect one hydrologic: component without altering others and have linked the use of ground and surface waters.

The use and management of water, then, is becoming more attuned to economic and natural resource conditions. For some regions, however, the most precise use of water requires more careful land management rather than water management per se. Rangeland agriculture, for example, involves managing plants and animals to provide optimal production from existing precipitation. Although the amount of water involved is small compared to irrigated agriculture, the land areas are vast and agricultural production from these regions is significant nationally.

THE TECHNOL0GIES

Water Management

Flexible Cropping

INTRODUCTION

In much of the semiarid region, low precipitation limits dryland crop production to some type of crop-fallow (noncropping season) system. Traditionally, farmers in the low rainfall areas of the northern and central Great Plains have strictly practiced this alternate-year rotation. In the slightly higher rainfall regions of the southern Great Plains, more intense rotations such as two crops every 3 years or annual cropping have been possible.

Dryland farmers in recent years have practiced methods of crop production that improve water storage during the fallow period, such as stubble mulch tillage and conservation tillage (ch. VIII). These technologies have helped increase the amount of water stored during the fallow period. Although there have been tradeoffs, for example, in weed control, this higher level of soil water is sufficient in some cases to allow farmers to grow crops each year,

Flexible cropping is an outgrowth of this development. In this system, a crop is planted when stored soil water and predicted rainfall are favorable for a satisfactory yield. When

Box X.—"Best Management Practices"

The importance of management practices for achieving various resource objectives has been long recognized. Conservation plans initiated by the Soil Conservation Service during the 1930's, for example, recommended certain management practices for controlling soil erosion. "Best management practices" for controlling nonpoint sources of water pollution were formally recognized in the Federal Water Pollution Control Act (FWPCA) of 1972 (Public Law 92-500) as amended by the Clean Water Act of 1977. States were instructed to develop and implement "best management practices" to reduce this type of pollution. The actual "best" practices were not specified in the legislation nor in subsequent regulations issued by EPA.

USDA has remained involved with the original conservation plans as well as more recent programs. The Clean Water Act authorized USDA to provide technical and financial assistance to farmers and ranchers for adoption of FWPCA's best management practices. While the program has moved slowly, it has spurred recognition that combinations of practices applied at the watershed level are most likely to meet multiple objectives: water conservation, erosion control, clean air, sustained food and fiber production, wildlife habitat, and recreational lands.

Computerized agricultural models make the evaluation of management packages simple and effective. For example, the long-term effects of weather and the implementation of new tillage practices can be tested locally and regionally before investments are made. A variety of agricultural models are available for these and related purposes. These include: EPIC (Erosion Productivity Impact Calculation), CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems), and SWAM (Small Watershed Model).

While technology exists for evaluating management practices, it has not been used to prepare integrated-management packages for farmers. Some people believe that an adoption bottleneck has resulted. Debate continues regarding who (i.e., public or private, Federal or non-Federal groups) should be responsible for putting together management packages. It is unlikely, however, that USDA's Agricultural Research Service (ARS) will assume major responsibility. The portion of the ARS budget allocated to integration of agricultural systems is expected to increase from 2 percent in 1982 to only 3 percent in 1990.

SOURCE: U.S. Department of Agriculture, Agricultural Research Service, "Agricultural Research Program Plan, &Year Implementation Plan, 1984-1990" (Washington, D. C.: U.S. Government Printing Office, 1983).

crop prospects are not favorable, no crop is planted, and a field is left fallow to store additional soil water.

ASSESSMENT

Flexible cropping systems were developed in the last few years for use in the northern Great Plains, Such systems have wide potential application throughout the Great Plains, but detailed procedures have yet to be developed for their use.

Success of a flexible cropping system requires a combination of preplanning, in-season, and postharvest practices. Before planting, a farmer assesses root-zone water-supply required for planting time and determines predicted seasonal precipitation for the growing season. Soil characteristics, crop-water requirements, and depth of rooting for different crops are also considered. If a farmer decides that soil moisture and predicted precipitation are sufficient, tillage operations are timed to maximize the water available to the crop, Fertilizer is applied to stimulate root growth during the growing season, Weed control and snow management are used after harvest to collect precipitation for the next growing season.

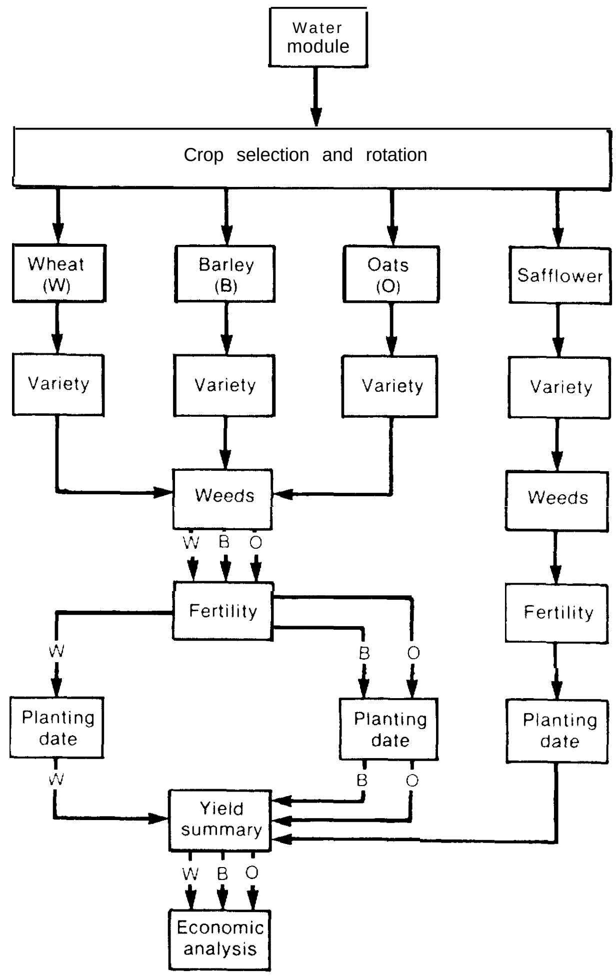
It is difficult for an individual farmer to evaluate all of these factors, and thus computerized management guides and users' manuals have been developed. In Montana, for example, these materials help farmers decide the best cropping and soil management options for wheat, barley, oats, and safflower based on stored soil water and expected growing season precipitation (figs. 69 and 70),

Besides making more systematic and optimal use of stored soil-water supplies and growing season precipitation, research indicates that the flexible cropping system may prevent the formation of saline seeps (ch. VIII), since soil water is used before it moves below the root zone.

Many of the limitations associated with flexible cropping systems are similar to those experienced with other water-conservation technologies, For example, if plant-barrier systems are used to trap winter snow. weeds mav in-

Figure 69.—Crop-Management Model for Flexible Cropping

This model, developed in Montana, depicts grain yield as a function of water supply crop variety weeds fertility planting date and rotation. Management decisions and crop information are then provided to the user, who types responses to questions asked by the computer



SOURCE: P. O. Kresge and A. D. Halvorson, *Flexcrop User's Manual Computer-Assisted Dryland Crop Management*, Montana State University Cooperative Extension Service Bulletin 1214, Bozeman, Mont., 1979.

crease. If conservation tillage is employed, managers may have difficulty seeding crops into the resultant residue. Where snow *is* collected, water might not filter properly into frozen soil.

Flexible cropping systems also have a unique set of management limitations. Crop rotations are a highly effective way to avoid weed, in-

Figure 70.—Sample Crop-Management Worksheet

Soil water

Moist soil depth (ft)[a]	Soil texture[a]	Weather location[a]	Date soil-water measured[a]

Crop information

Previous crop[a]	Crop to be grown[a]	Variety choice[b]	Variety code[a]

Weed information

Wild oat infestation[a]	Control[a]	Broadleaf infestation[a]	Control[a]

Fertility

NO_3 – N to 4 feet lb/A[b,c]	N application rate lb/A[a,c]	Type of P soil test[b]	Soil test P[b]	P application rate lb/A[a,c]

Seeding date[a]

[a]Required for operation of program
[b]Can be optional.
[c]lb/a = pounds per acre.

An illustration of the information needed for the flexible cropping model.

SOURCE P O Kresge and A D Halvorson, *Fexcrop* User's Manual Computer *Assisted Dryland* Crop Management Montana State University Cooperative Extension Service Bulletin 1214. Bozeman. Mont 1979

sect, and disease buildup, but they have become rare in many regions because of past economic constraints, Therefore, little information exists to guide farmers in choosing possible crop rotations. In addition, some crops* are difficult to work into a flexible cropping system because they are planted in the fall before most water is accumulated and total water supplies are known.

Also, social and economic considerations currently limit employment of flexible cropping systems. Farmers generally view flexible cropping as a riskier approach than traditional crop-fallow practices, one that requires a higher management commitment. Some farms may have the labor and time to conduct the intensive soil-water monitoring needed for its application, but total reliance on a flexible cropping system often requires resources (e.g., labor, capitol, and access to agricultural consultants who can assist in monitoring and planning operations) available most readily to large operations. Federal policies governing crop diversions and set-asides may pose a further barrier to adoption. For example, policies requiring farmers to reduce acreage in order to be eligible for certain benefits (e. g., commodity loans and disaster payments) may be in effect in years when soil-water conditions would allow full production. In other cases, set-asides may increase flexibility by allowing installation of soil- and water-conserving practices without losing a crop.

Irrigation Scheduling

INTRODUCTION

Traditionally, many growers schedule irrigation periods by examining crop appearance and soil-water conditions and judging future weather. Others time water applications by the calendar. Still others are forced to schedule irrigations by water delivery rotation systems. These scheduling procedures give generally satisfactory results but may not make the most efficient use of water, maximize crop yields, or save energy.

The concept of scientific irrigation scheduling" has received much attention in recent years. It takes into consideration:

- precipitation and evapotranspiration since the previous irrigation,
- allowable soil-water depletion at the particular growth stage of the crop, and
- expected precipitation and crop-water requirements before the next irrigation.

To assess the need for water application, two technically sophisticated methods are used: 1) environmental and plant monitoring, and 2) a water budget technique. In the first method, tensiometers, electrical resistance gypsum

* For example, winter wheat.

*The prediction of the time and amount of water required for the next and future irrigations.

blocks, or neutron probes are used to measure soil water (ch. VIII), Plant water stress is inferred through use of infrared thermometers or pressure chambers, Some of these types of monitors do not indicate how much irrigation is needed.

In the water budget method, an alternative to environmental monitoring, the crop root zone is visualized as a reservoir of available water. Water is withdrawn from the root zone through evaporation or drainage and added through rainfall and irrigation. If the volume of water in the root zone—the amount of water that can be drained without stressing the plant (or the allowable depletion)–and the depletion rate (or evapotranspiration) are known, the date of the next irrigation can be predicted. Coupled with accurate weather forecasts, this method allows for accurate irrigation scheduling.

ASSESSMENT

Irrigation scheduling services (ISS) are provided to about 1 million acres in the Western United States by Federal and State agencies and private consultants (1 3). Most services are based on computer predictions of time and amount of irrigation.

Several advantages of irrigation scheduling services have been noted by researchers. Limited information indicates that crop yields with irrigation scheduling can be increased by an average of 10 to 30 percent primarily a result of proper timing and sufficient water application although other research has been unable to document significant increases. Scheduling may reduce the number of irrigations per season by making maximum use of soil water and rainfall, It may also help to reduce pollution of ground water because less excess water is percolated through the soil. In areas where electricity is used for pumping irrigation water, irrigation scheduling may also help manage peak electrical loads. Moreover, because plant environmental conditions are better known, this technology permits managers to plan water rotations among fields, pesticide applications, tillage operations, and other activities to minimize crop stress and yield reductions.

A number of technical and social factors affect the adoption of irrigation scheduling. First, the effectiveness of the system depends on the total water application and measurement system, including delivery, application, and irrigation. Before scheduling can be implemented, each of these systems should be evaluated to determine capacity, needs, flexibility, and limitations. Surface water delivery systems to the farm in some areas are fixed and may not be adapted to scheduling techniques based on crop-water needs because of the short notice involved (ch. VII).

Second, field verification of computer predictions about environmental conditions is necessary because of site-specific variability in the depth of water applied at each irrigation, the crop rooting depth, soil water storage capacity, allowable depletions, effective rainfall, and crop evapotranspiration. These field checks require competent and trained personnel who can communicate effectively with growers. For example, the Bureau of Reclamation has developed an irrigation management service program to help irrigators schedule water deliveries and application. Private agricultural consultants have also developed scheduling services, These dual efforts raise questions about the government and private role in onfarm water management (19).

Third, irrigation scheduling services are adopted when definite economic benefits can be readily identified by the grower, since these services are costly and beyond the means of many farmers. Inexpensive and readily available water supplies reduce the incentive to implement scheduling. As discussed in chapter V, water law may often inhibit farmers from conserving irrigation water onsite since the water “saved” does not become available for other uses on the same farm. Again, the short-term economic incentive for adopting the technology may not be adequate, now, but this situation may change rapidly if water costs reflect more closely replacement value of water,

Fourth, there is general skepticism that yields can be improved by altering irrigation practices. Scheduling services can increase net income to growers to the extent that the level of

Box Y.—Water Management in Israel

Israel has limited freshwater supplies but a rapidly growing population. Consequently, water-management strategies during the 1980's have shifted from development of new supplies to management of water demand. Nationalized water resources, a national supply system, and elaborate programs of technical assistance to water users are important components of this approach. These arrangements were possible in part because Israel is a small country and neither farm groups nor water-rights holders existed to oppose their initiation.

Several methods are used to manage water demand: metering, pricing, and allocation. All water users are metered and receive annual licenses for ground water, runoff, and sewage effluents. Water prices are adjusted nationally, and larger water users pay higher prices. Water costs are high, reflecting the true scarcity of the resource. Each farm is allocated its water annually, an allocation which may be decreased the following year.

As a result of these policies, Israelis a leader in several water-use technologies. These include wastewater reuse, use of brackish water, and specialized irrigation systems. A close-working relationship between researchers and farmers has also ensured that research results are quickly adopted and often cooperative groups of farmers manufacture new instruments themselves.

SOURCE: U.S. Congress, Office of Technology Assessment, "Water and Agriculture in Arid Lands: selected Foreign Experience-A Background Paper" (Washington, D.C.: U.S. Government Printing Office, OTA-BP-F-2O, May 1983).

some production input is decreased, the quality of the crop is increased, or yields are increased. Among those who provide scheduling services, there may be an overemphasis on the degree to which yields can be improved or irrigation can be reduced.

In sum, irrigation scheduling is a necessary but incomplete management tool for increasing irrigation efficiencies. It can help to conserve water when precise control is available throughout the water distribution system.

Wastewater Reuse

INTRODUCTION

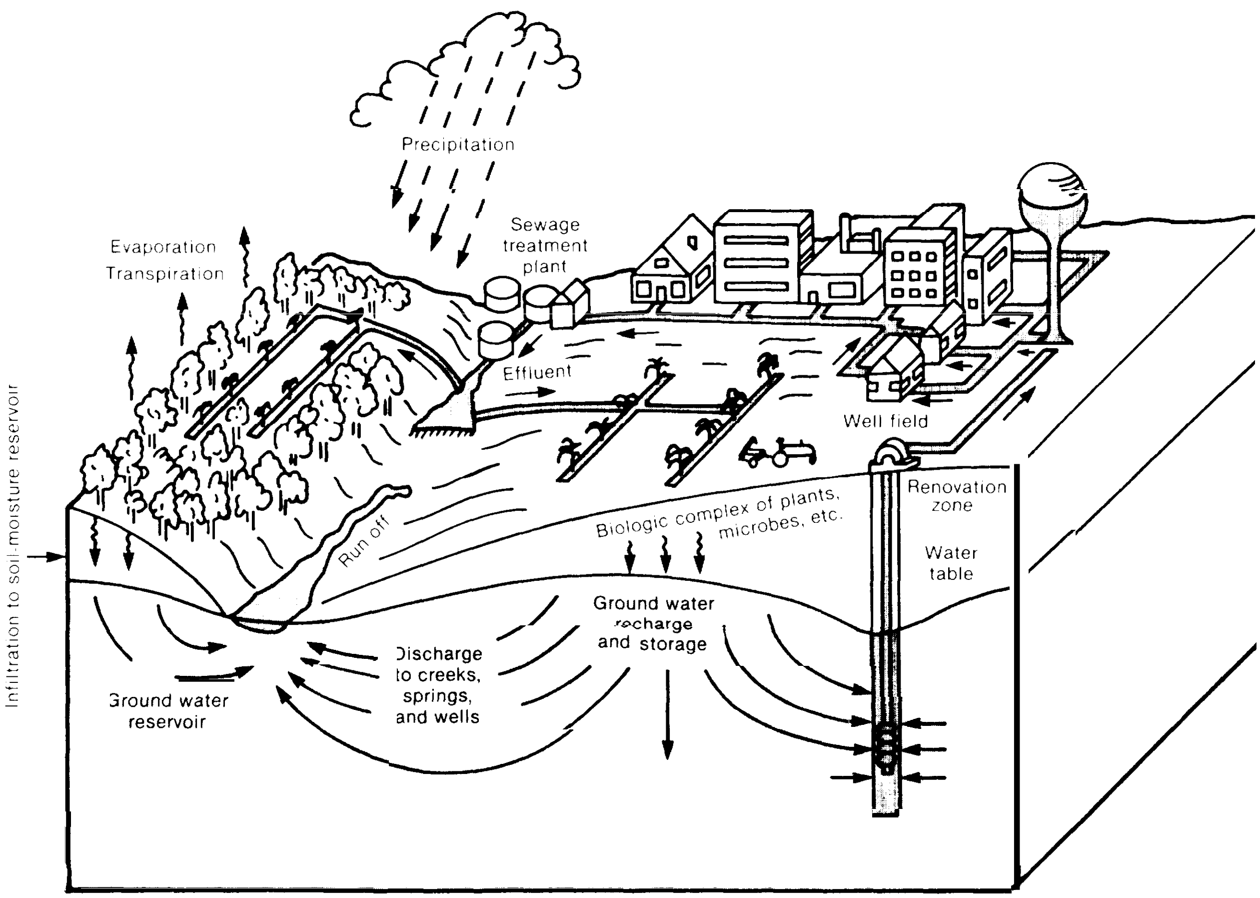
Wastewater reuse, defined as the use of land to renovate sewage effluent from municipal or industrial sources, is receiving increased attention as a possible way to augment irrigation water supplies and to reduce the water pollution that might otherwise occur if such wastewater were released directly to waterways. Those who advocate wastewater reuse consider that wastewater and the nutrients it contains are resources rather than refuse. Wastewater provides water and nutrients to plants, In return, biological and chemical processes that occur in the soil, micro-organisms, and plants are thought to cleanse the wastewater, According to supporters of this practice, renovated, safe water may then percolate downward to recharge the ground water reservoir or be discharged directly to surface water (fig. 71).

The idea of using land to treat wastewater is not new. Parker (22) notes that "treatment and disposal of sewage by land extensive schemes of irrigation is the oldest form of the modern methods of purification, " These methods dominated U.S. municipal sewage-treatment systems until the early 20th century, but gradually diminished in importance as metropolitan areas expanded, large expanses of land adjacent to urban areas became limited, and concerns grew about possible public health and water-quality effects. Sewage treatments that used less land were developed as well.

Since the early 1970's, interest in land application technologies has revived, In part, this interest reflects a greater public awareness of the costs of treatment to meet health standards and of potential pollution and degradation caused by the discharge of partially treated wastes into waterways. It also reflects concerns about the growing scarcity of unallocated surface water supplies and rates of ground water depletion, especially in the West. Finally, Fed-

Figure 71.—The Wastewater Renovation Cycle

After treatment at a sewage-treatment facility, effluent is applied to the land. Biological and chemical processes that occur in the soil and plants provide further treatment for the wastewater. Renovated water then percolates to the ground water or is discharged directly to the surface water.



SOURCE William E Sopper "Surface Application of Sewage Effluent, " *Planning the Uses and* Management of *Land,* Marvin T Beatty, et al (eds) (Madison, Wis.: American Society of Agronomy, 1979), pp 633-663 (No 21 in the series *Agronomy)*

eral actions—e.g., passage of the Water Pollution Control Act of 1972 (Public Law 92-500)–have stimulated interest in reuse technologies to balance treatment costs.

Wastewater Treatment Methods

Wastewater contains two major categories of contaminants: biological and chemical. Biological contaminants include bacterial or viral pathogens and intestinal parasites. Chemical contaminants include substances such as nitrates, sodium, heavy metals (e. g., cadmium, lead, and zinc), oil, grease, and pesticides,

Levels of treatment generally recognized for wastewater are primary, secondary, and tertiary. This classification is based on the removal of suspended solids and on the reduction of biochemical oxygen demand (BOI))-i.e., the oxygen needed to meet metabolic needs of aerobic micro-organisms in water containing organic matter. Primary treatment consists of mechanical and physical removal of suspended solids. This process is estimated to remove approximately 35 percent of the BOD and 60 percent of the suspended solids in raw sewage water (26).

Secondary treatment introduces biological processes—e.g., activated sludge or trickling filters—to remove much of the remaining suspended solids and organic matter. Secondary treatment will remove from 80 to 95 percent of the BOD and suspended solids (26).

Tertiary, or advanced wastewater, treatment is used after primary and secondary treatments to reduce BOD further, remove suspended solids, lower nutrient concentrations, and improve the effectiveness and reliability of disinfection. Land application of wastewater is considered one method of tertiary treatment along with others such as chemical coagulation, clarification, filtration, activated carbon treatment, and reverse osmosis.

Advanced wastewater treatment by land application can be achieved in a variety of ways, depending on the goal of the treatment, the composition of wastewater, and characteristics of the waste site. The three most commonly used methods for land application are slow-rate irrigation, overland flow, and rapid infiltration-percolation, Table 76 compares the three methods by use objectives.

Slow-rate irrigation (fig, 72-A) is probably the method used most often and with most potential for agricultural use. In this process, wastewater is applied to the soil surface by a fixed or moving sprinkler system or by surface irrigation. Water application rates are generally low and are largely determined by climate, soil, and the water and nutrient needs of the crops. Treatment proceeds as vegetation and soil micro-organisms act to remove and alter wastewater as it percolates through the soil.

Overland flow reuse systems (fig. 72-B) also rely on a vegetative cover to effect waste treatment but differ from slow-rate methods because crop production is usually not a major objective, In this process, wastewater is applied over the upper parts of vegetated terraces and allowed to flow in a thin sheet down the relatively impermeable surface to runoff collection ditches, Only small amounts of wastewater infiltrate into the soil or percolate to the ground water. Renovated water that is collected may be reused or discharged directly to surface water. Treatment occurs by physical, chemical, and biological means.

Table 76.—Comparison of Irrigation, Overland Flow, and Infiltration-Percolation of Municipal Wastewater

Objective	Type of approach: Irrigation	Overland flow	Infiltration-percolation
Use as a treatment process with a recovery of renovated water [a]	0-70 "/0 recovery	50-800/o recovery	Up to 970/0 recovery
Use for treatment beyond secondary:			
1. For BOD[b] and suspended solids removal	98 + °/o	92 + %	85-990/o
2. For N removal	85 + %[c]	70-900/0	0-50 "/0
3. For P removal	80-99°/0	40-800/o	60-950/o
Use to grow crops for sale	Excellent	Fair	Poor
Use as direct recycle to the land	Complete	Partial	Complete
Use to recharge ground water	0-70 "/0	0-10 "/0	up to 97 "/0
Use in cold climates	Fair[d]	d	Excellent

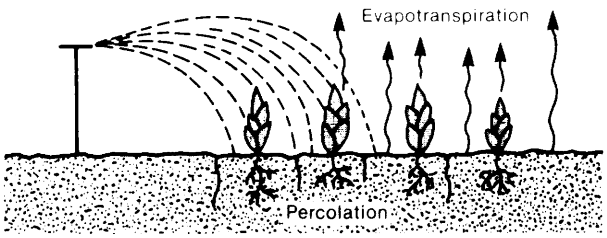
aPercentage of applied water recovered depends on recovery technique and the climate
bBOD = Biochemical oxygen demand
CDependent on crop uptake
dConflicting data—woods Irrigation acceptable, cropland irrigation marginal
'Insufficient data

SOURCE William E Sopper, "Surface Application of Sewage Effluent," *Planning the Uses and* Management of *Land,* Marvin T Beatty, et al (eds) (Madison, Wis American Society of Agronomy, 1977), pp *633663 (No 21* in the series *Agronomy)* (Original source U S Environmental Protection Agency, "Process Design Manual for Land Treatment of Municipal Wastewater, " EPA 62511-77-008 (Washington, D C , 1977).

Figure 72.—The Major Types of Wastewater Treatment

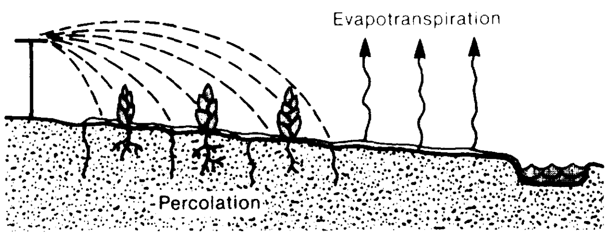
A. Slow-rate irrigation

Wastewater IS applied to the soil surface and allowed to percolate downward Treatment proceeds as soil, vegetation, and soil micro-organisms remove nutrients and suspended solid material.



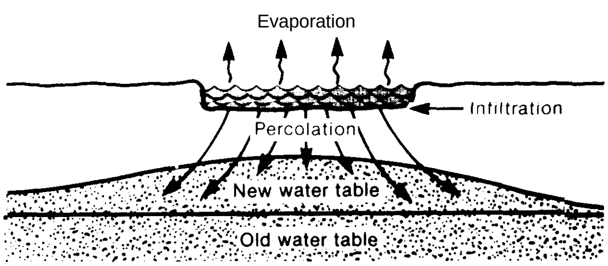
B. Overland flow reuse

Wastewater IS applied to a sloping surface and allowed to flow over the soil surface to runoff collection ditches Treatment IS a result of physical, chemical, and biological processes



C. Rapid-infiltration percolation

Wastewater IS applied by flooding or sprinkling to highly permeable soils in basins. As the wastewater percolates Into the soil renovation occurs



SOURCE William E Sopper "Surface Application of Sewage Effluent," *Planning the Uses and Management of Land,* Marvin T Beatty, et al. (eds.) (Madison, Wis. American Society of Agronomy, 1979), pp. 633-663. (No. 21 in the series *Agronomy)*

Rapid infiltration-percolation, the third method, uses less land area to effect treatment than do the other two methods. The main objective in this system is ground water recharge (fig. 72-C). Wastewater is applied to highly permeable soils in basins by flooding or sprinkling. The basins may or may not be vegetated. Renovation occurs through natural processes in the soil as water percolates downward.

The degree of success for wastewater treatment varies with the type of method used to apply wastes, Table 77 shows expected treatment performance for these three processes.

ASSESSMENT

Municipal wastewater is now used for irrigation, However, information on the number of communities that use land treatment for sewage renovation and the number of individuals who use wastewater to irrigate agricultural crops is inexact, because funding for these systems may be through the Federal Government, industry, or private sources, With Federal funding, estimates are that approximately 1,000 municipalities use land application to treat wastes (31). Unpublished data from the U.S. Geological Survey (USGS) indicate that in 1980, 0,5 billion gal/day of effluent were used for irrigation compared to 290 billion gal/day of fresh surface water and 88 billion gal/day of fresh ground water.

Some communities use municipal wastewater for irrigation for parks, golf courses, and greenbelts and Federal and State guidelines have been developed for its application (e.g., 22,36). In California, for example, irrigation return flows of relatively good quality are applied to wetland areas to maintain natural vegetation. These areas are then used for cattle grazing in summer and hunting in the fall. Chemical wastes from potato processing plants have also been used for irrigation. In spite of these signs of acceptance, widespread adoption of reuse systems for most agricultural crops is hindered by numerous biological, social, economic, and legal questions and a lack of long-term research on the subject. Chapter IV discusses some of the more serious public health questions that still need answers before full-scale programs should be adopted. Table 78 presents a summary of issue areas that require resolution.

Three examples illustrate the complexity of these issues. First, regarding the question of

Table 77.—Expected Quality of Treated Water From Land Treatment (mg/liter)

	Slow rate[a]		Rapid infiltration[b]		Overland flow[c]	
Constituent	Average	Maximum	Average	Maximum	Average	Maximum
BOD	<2	<5	2	<5	10	<15
Suspended solids.	<1	<5	2	<5	10	<20
Ammonia nitrogen as N . .	<0.5	<2	0.5	<2	0.8	<2
Total nitrogen as N	3	<8	10	<20	3	<5
Total phosphorus as P	<0.1	<0.3	1	<5	4	<6

[a]Percolation of primary or secondary effluent through 1.5 m (5 ft) of soil.
[b]Percolation of primary or secondary effluent through 45 m (15 ft) of soil
[c]Runoff of municipal wastewater over about 45 m (150 ft) of slope

SOURCE William E Sopper Surface Application of Sewage Effluent, " *Planning the Uses and Management, of Land,* Marvin T Beatty et al (eds) (Madison, Wis. American Society of Agronomy, 1977), pp 633-663 (No 21 in the series of *Agronomy)* (Original source U S Environmental Protect Ion Agency "Process Design Manual for Land Treatment of Muntcipal Wastewater, EPA 62511-77008 (Washington, D C 1977)

land productivity with reclaimed water, data indicate that the yields of crops irrigated with wastewater usually increase or remain the same (9,26), but crops seem to vary in their tolerance to wastewater application (table 79). For example, research in Hawaii on sugarcane tested the dilution of wastewater required for optimal sugar yield (18). Five treatments for the 2-year cane cycle were tested: 1) conventional irrigation water, 2) 12.5-percent effluent diluted with irrigation water, 3) 25-percent sewage water, 4) 50-percent effluent diluted with ditch water, and 5) effluent the first year and irrigation water the second year. Scientists found that sugar yields for wastewater concentrations up to 25 percent, or for wastewater the first year and irrigation water the second year, were equal to those from conventional irrigation supplies. When wastewater concentrations increased to 50 percent, however, sugar yields and juice quality declined significantly. The researchers concluded that chlorinated, secondarily treated sewage effluent with nitrogen concentrations could be used in furrow irrigation for the 2-year crop cycle of sugarcane if wastewater were diluted with freshwater so that the concentration of effluent was 25 percent or less. They cautioned, however, that effluent quality must be constantly monitored for nitrogen content, pesticides, heavy metals, and pathogenic viruses. Such substances in the soils or waterbodies could prove difficult, if not impossible, to eliminate (chs. IV and X). In addition, field workers were warned to practice careful sanitation and personal hygiene to protect against infection.

A second illustration provides a sample of the economic questions that surround application of wastewater for irrigation. Although effluent was generally recognized as a valuable resource for water and nutrients, few farmers actually measured the fertilizer value of the water. Similarly, those in local governments responsible for the operation of reuse systems acknowledged the economic value of the effluent but had not established procedures to charge landowners or farm operators for the value that they received. Instead, they took the view that landowners performed a service in disposal of municipal waste effluent.

Third, with regard to social concerns, public reaction may be an obstacle to wastewater reuse. A survey of selected California communities indicated that respondents favored water treatment options that protected public health, enhanced the environment, and conserved scarce water (5). However, use of reclaimed water for ground water recharge and drinking supplies was perceived as a threat to human health. Effluent used for industrial purposes or for irrigation of animal feed and fiber crops was considered to be an acceptable practice (6). The inconsistency arises when contaminants from effluent reach the ground water secondarily, as the result of its use in industry or irrigation.

Wastewater reuse has been adopted by relatively few communities and farmers in the United States. It can potentially supplement irrigation water supplies and reduce reliance on added fertilizer, but generates many questions

Table 78.—Summary: Issues Surrounding Water Reuse for Irrigation

Resource issues:

1. Effluent quality:
   - —Nutrient content
   - —Heavy metal content
   - —Pathogen content
2. Soil productivity"
   - —Salt buildup
   - —Toxicity buildup
   - —Viral contamination
   - —Physical degradation
3. Crop production:
   - — Fertilizer and water requirements
   - —Crop growth and yields
   - —Crop uptake of nutrients
   - —Crop uptake of toxics and pathogens
4. Animal health.
   - —Animal uptake of nutrients
   - —Animal transmission of pathogens to human consumers
5. Ground water quality
   - —Path of water to water table
   - —Quality of water reaching ground water
6. Air quality (with sprinkler irrigation)
   - —Health effects for workers and nearby residents
   - —Odor considerations

Social and economic issues:

1. Human health effects:
   - —Contact with effluent by farmworkers
   - –Contact with plant and animal products by consumers
2. Social factors
   - —Public attitudes toward application
   - —Public attitudes by consumers of products
   - —Attitudes of nearby residents
3. Economic considerations
   - —Water pricing
   - —Transportation costs
   - —Subsidies for those who use water
   - — Facilities for water storage
   - —Value in alternate uses
   - —Type of material contained in water

Institutional issues:

1. Water-treatment facilities
   - —Adequacy and reliability of treatment prior to application
   - —Adequacy of storage facilities during periods of nonapplication
2. Monitoring
   - —Need for monitoring air, effluent, ground water, crop, and soil quality
3. Legal issues
   - —Ownership and sale of water
   - —Water rights
   - —Liability for damages
   - —Responsibility for monitoring
   - —Guidelines for water reuse (e. g., crops to be grown, amount of water to be applied)
   - —Effect on downstream users (third parties), if water previously was part of return flows

SOURCE William H. Bruvold Agricultural *Use of Reclaimed Water* unpublished paper prepared for National Science Foundation January 1982 Off Ice of Technology Assessment, 1982

Table 79.—Crop Yields at Various Levels of Application of Wastewater, Pennsylvania State University

Crop	Wastewater Application Rates. inches per week[a] 0[b]	1,0	2.0
	(bushels/acre)		
Wheat	48	45	54
Corn ., ...	73	103	105
Oats. ., ...	82	113	88
	(tons/acre)		
Alfalfa	22	3.7	51
Red clover ., ...	2,4	4.9	4,6
Corn stover	3.6	7.3	8.5
Corn silage	4.3	6.4	6,0
Reed canary grass ., . .	1.4	—	5.0

aMetric units in original document have been converted to English units.
bControl areas received commercial fertilizer ranging from 10 tons/acre of 0-20.20 for oats to 40 tons/acre of 10-1010 for corn

SOURCE William E Sopper 'Surface Application of Sewage Effluent *Planning the Uses and Management of Land* Marvin T Beatty et al (eds) (Madison, Wis American Society of Agronomy 1977) pp 633-663 (No 21 in the series *Agronomy)* (Original source U S Environmental Protection Agency, 'Process Design Manual for Land Treatment of Municipal Wastewater, " EPA 625/1-77-008 (Washington D C 1977))

on long-term impacts for soil and water quality and, ultimately, public health. Wider application of reuse systems will require careful planning and monitoring by municipalities and irrigators. The costs and danger of handling wastewater will have to be balanced with economic benefits of its reuse. In addition, when applied on a massive scale, questions are raised about the impacts of this water shift on other aspects of the hydrologic cycle, especially stream flow, if the treated water has previously been part of return flows. Moreover, legal considerations for downstream users may be complex. Much research has been done on this topic, but additional long-term research on the effects of these systems on crops, soils, ground water, and human and animal consumers is needed.

Water Management by Conjunctive Use

INTRODUCTION

The concept of conjunctive use is predicated on shifts between surface and ground water use and storage, During periods of above-average precipitation, or seasons of above-average runoff, surface water would be used to the maximum extent possible to fulfill various water requirements. Any surplus water would be used to recharge ground water supplies and raise ground-water levels. During dry periods, surface water supplies would be supplemented by ground water reserves.

ASSESSMENT

Whether conjunctive management of a basin's water is technically practical depends on local geology and the extent to which ground water resources are manageable over a range of water levels. There must be space to store recharge water, there must be water in storage when and where it is needed, and there must be the physical facilities and energy available to transport surface and ground water.

Management by conjunctive use requires careful planning to optimize the use of the available surface and ground water resources. Detailed, site-specific engineering and economic analyses are needed to determine optimal mixes of surface and ground water storage.

A conjunctive use management approach requires more information than is commonly necessary for the use of either surface or ground water resources separately. In the most general terms, these information requirements include detailed data on surface and ground water resources, the geologic conditions of the basin, interconnections of surface and ground water supplies, water-distribution systems, historical and projected water-use patterns, and wastewater disposal practices.

Commonly, except perhaps in the simplest situation, mathematical models are required to describe the reaction of the ground water reserves to fluctuations in natural and artificial recharge and to varying pumping rates. Such models are available, but they vary widely in capability and limitations and must be used carefully. State governments indicate the desire for more resource models, while the Federal Government needs to better coordinate the use of models among various agencies (32),

Ultimately, decisions concerning the feasibility of conjunctive use management of water resources must also include an assessment of the relative economic benefits of constructing additional surface storage facilities, the increased complexity of conjunctive management approaches, and the cost of energy to pump water from aquifers. Because each project will be unique, no universal rules exist governing the economics of this approach to water management. Some of the advantages and disadvantages are listed in table 80.

Enclosures for Plants and Fish

INTRODUCTION

Greenhouses are commonly used in the United States to grow horticultural products such as flowers and houseplants. In Europe, enclosures are used also for crops primarily of very high economic value, such as table vegetables. In the Middle East and Asia raising fish in enclosures is an ancient applied science. Aquiculture in various forms provides over 40 percent of total fisheries production in some countries but only about 2 percent of total fisheries products (7).

Many features of arid and semiarid lands make them especially suitable for growing plants or fish in enclosures: solar energy is abundant, growing seasons are long, and winters are often mild, Typically, the efficiency with which water is used is very high, and intensive management allows for the most efficient use of other substances such as fertilizers and pesticides.

Plant and fish enclosures vary widely in scale. Some are major corporate enterprises requiring large investments to initiate. Others are suitable for production of a few items for household use and local sales.

ASSESSMENT

Experiments around the world with highly sophisticated systems show that crop yield in controlled environments is several times that of field-grown crops. For example, enclosures in Mexico and Abu Dhabi yielded almost 20 different fruits and vegetables at production levels often several times higher than field-grown equivalents with about one-third the use of water and significantly shorter growing seasons.

Table 80.—Conjuctive Use of Surface Water and Ground Water Resources

Advantages	Disadvantages
1. Greater water conservation	1. Less hydroelectric power
2. Smaller surface storage	2. Greater power consumption
3. Smaller surface distribution system	3. Deceased pumping efficiency
4. Smaller drainage system	4. Greater water salinity
5. Reduced canal lining	5. More complex project operation
6. Greater flood control	6. More difficult cost allocation
7. Ready integration with existing development	7. Artificial recharge is required
8. Facilitated stage development	8. Danger of land subsidence
9. Smaller evapotranspiration losses	
10. Greater control over outflow	
11. Improvement of power load and pumping plant use factors	
12. Less danger from dam failure	
13. Reduction in weed seed distribution	
14. Better timing of water distribution	

SOURCE D K Todd, *Groundwater* Hydrology, 2d ed (New York John Wiley & Sons, 1980) (Original source F B Clendenen, Economic Utilization of Ground 'Water **and Surface Water Storage Reservoirs, " presentation to American Society of Civil** Engineers, San Diego. Calif , February 1955)

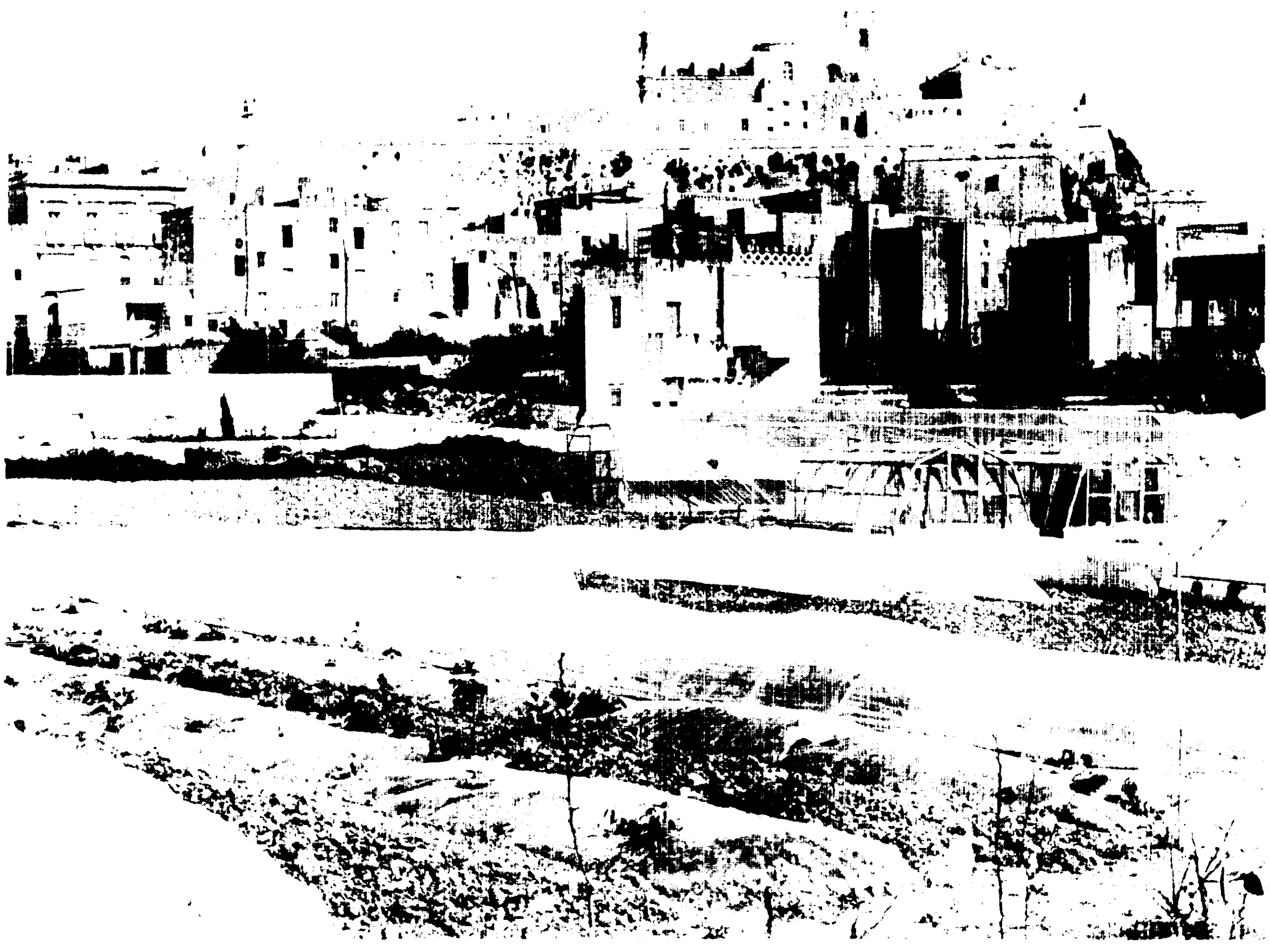


Photo credit *Food and Agriculture* Organization — *U. Pizzi*

Many types of plant enclosures exist. These plastic tunnels in Malta, protect horticultural crops, such as grapes, vegetables, and flowers

These results are possible because the systems are completely or nearly closed, humidity remains high, and irrigation water is recycled. Enclosures also insulate the grower from the unpredictable climate of arid and semiarid regions and help stabilize production, Marketing is also independent of weather, and it can be timed to take advantage of highest prices.

Scientists and engineers continue to refine technical aspects of these structures. In the face of rising energy costs, systems that use solar energy appear promising for long-term production. Bettaque (3) described “eco-islands in the desert” that use solar energy and saltwater to heat and cool greenhouses while distilling freshwater. He found that such enclosures use minimal amounts of fossil fuel energy, have capital costs comparable to conventional green houses, and that increased crop yields are possible with little technical sophistication. Similar Israeli systems use a closed cycle of freshwater to absorb solar radiation. Practices that may not be technically possible in open fields, such as atmospheric enrichment with higher levels of carbon dioxide, are also being attempted in enclosures (24).

Plant enclosures will not produce large amounts of inexpensive food because the capital costs for large installations are usually high and operating such enclosures may be labor- and energy-intensive. While basic agronomic crops grow well in enclosures, they are not expected to be grown commercially in this way in the foreseeable future. The development and use of less common types of plant enclosures face many of the same constraints listed below for aquiculture. For example, most agricultural experts are not familiar with integrated plant/fish enclosures or greenhouses, such as attached solar enclosures of unusual design.

Some aquiculture (or a combination of aquiculture and plant production systems) may be possible in U.S. arid and semiarid zones, Preliminary tests suggest that aquiculture in the West is feasible (27). For instance, recent research in Nevada has shown that shrimp can be grown in ponds heated by geothermal springs or by warm wastewater from electric generating plants (30). Several Western States have extensive hatchery and release programs that could be further developed. Generally, the potential for aquiculture is rated highly. There is an extensive market for seafood in the United States and more than 50 percent is imported (7). Few aquiculture attempts have been undertaken commercially in the Western United States, however, and the further development of integrated plant/fish and fish systems faces severe constraints. For example, water requirements for fish culture could be substantial and require diversions from other uses. Other problems include:

- inadequate funding for research and development;
- poor marketing practices;
- inexpensive imported products;
- regulatory controls, especially standards for waste discharges;

Photo credit: USDA Soil Conservation Service

The potential for aquiculture in the Western United States is high. In Texas, these channel catfish have been seined from a pond and separated from other fish, From here, they will be transported to a feeding pond

- uncertain availability of high-quality water;
- lack of trained personnel; and
- overcoming a bad image from past failures.

For these and other reasons, aquiculture is not expanding rapidly in the United States. Government, industry, and academic experts have recommended that the United States develop a national aquiculture development plan and improve coordination of present Federal programs in order to increase aquiculture's contribution to fisheries production.

Land Use Management

Most farms and ranches produce one product and use highly energy-intensive practices such as chemical fertilization and pesticides. With uncertain economic and resource conditions, such as increasing energy costs and unknown water availability, such specialization may involve greater risks. Therefore, technologies that integrate different types of land use and different types of agricultural and nonagricultural products hold promise for stabilizing economic risk and are perceived by some as the direction of the future.

The technologies discussed in this section are diverse and reflect a spectrum of agricultural philosophies. For example, multiple land use on rangelands falls within accepted traditional practice, but the various types of alternative agriculture are, by definition, not traditional technologies.

Multiple Use of Rangeland

INTRODUCTION

Rangelands in arid and semiarid lands are being used increasingly by different kinds of people for very different purposes. This is an important feature of publicly owned rangelands and is required by law for Federal lands. This concept is also being developed for some privately owned lands. Under these conditions, the highest animal, plant, or water production per unit area is not necessarily maximized. For example, plants that are "unproductive" in agricultural terms may be allowed to remain along streambanks for the other important amenities that they provide. When the efficiency of water use is measured in terms of all products per unit of water used, such multiple uses may be more water-use efficient than would traditional single uses such as grazing.

Major present multiple uses of rangeland include livestock and wildlife grazing, recreation, and mining. Uses that are less important include harvesting nonforage plant products, such as seeds and nuts, providing military reservations and waste disposal sites, producing nonmeat animal products, and producing water for offsite use.

Al1 of these activities have hydrologic effects, some greater than others. However, the relative importance of each potential use and its impacts on water resources shift from area to area and continue to change. In some States, public rangelands provide a great deal of water-based recreation; in others, mining activity is concentrated on these sites.

ASSESSMENT

Range managers often operate without an adequate data base, making multiple-use management especially difficult. Because Western grasslands were altered by human settlement before data were collected, major gaps in the understanding of the structure and function of these areas exist. Early managers did not place high emphasis on data collection. Even now, the long-term effects of specific management practices are unknown. For example, the results of stocking rates recommended by the Bureau of Land Management for individual users are not systematically monitored.

Intensive management of any resource is made especially difficult under such circumstances. The tendency is to "maximize" all uses, leading to the nonsustainable use of the resource. Considerable debate has ensued recently over the results of applying the multiple-use concept to public range lands, Some contend that it wiIl diminish the value of public rangelands for grazing livestock. Others contend that multiple use discourages ranchers

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Photo credit" U.S Department of the Inferior, National Park Service

Federal lands provide a great deal of water-based recreation, including fishing, swimming, and boating

from overgrazing and will, in the long term, improve range conditions.

Many factors outside of the agricultural sector determine the future importance of multiple uses of all land types. The growing Western urban population has led to the increase in recreational use of rangelands. The search for new energy sources has stimulated mining activities. Some of these activities are discussed below.

Factors Determining Future Multiple Use of Rangelands

Wildlife.—Arid and semiarid rangelands provide habitats for a significant number of wildlife species, including mammals, birds, and fish. These animals attract large numbers of visitors to the region and are of great interest to residents as well. Wildlife considerations strongly influence water management on many rangelands, and intensive water management has important effects on wildlife. Technologies for wildlife management usually do not require additional supplies of impounded water but may result in increased rangeland productivity per amount of water used (21,27).

Wildlife species normally require freshwater of reasonably good quality. Water consumption rates are virtually unknown for most wildlife species, but they are not thought to be great. For example, total water consumption by big game animals may range from 100,000 to 130,000 acre-ft/year for the entire Western range (27). Water distribution and quality are more critical factors. Bighorn sheep are adapted for high water conservation, but their distribution depends on available drinking-water supplies. Mule deer populations show major changes if the nearest water supply is farther than 3 miles (38).

Inland rangeland fisheries depend on the maintenance of lakes, perennial streams, ranch ponds, and reservoirs. These features also provide habitat for waterfowl, an especially important rangeland resource in the northern Great Plains. Water levels must be consistently maintained for fish and waterfowl to survive. Sometimes this is not economically feasible and usually it is not legally required.

Irrigation in the same watershed may lower water tables and reduce both streamflow and riparian and upland wildlife habitat. Other agricultural practices, such as the use of chemical or mechanical methods to eliminate unwanted plants, alter the cover and food supply on which wildlife depend. After considering the major effects that agricultural practices can have on wildlife, the National Research Council (21) recommended that there be three requirements for optimizing all resources, including water and agricultural production. These are:

- promotion of attitudes encouraging stewardship of wildlife;
- additional critical research on conservation tillage, irrigation patterns, pesticide

effects, and nutrients in aquatic systems; and

- consistent public policies that use incentives to enhance fish and wildlife habitats.

Recreation.—Recreational use of rangelands has increased dramatically in recent years. Much of this activity is water-based, either directly—e.g., fishing—or indirectly —e.g., hunting. Some recreational activities make extensive use of shorelines of existing water bodies. Range managers sometimes develop new sources of water from natural seeps, low-yield springs, and wells for these uses. These developments supplement and expand water supplies on rangelands. However, goals for livestock production and recreational opportunities sometimes are incompatible and management is difficult. In Texas, for example, where deer and other wildlife are hunted through leases, ranch managers often give more attention to providing accommodations to hunters than to actual management of the deer herds (8),

The income from hunting leases to a rancher with private lands can be substantial. In Texas, where there are few public lands available for hunting and most private lands are protected from trespassing, hundreds of thousands of acres are leased for hunting each year at prices of up to $10 per acre (8). Income from leasing in many cases exceeds that from the sale of livestock, the primary use of the land. Hunters paid landowners $108 million for leases in 1971 (2], and the average cost of each lease has increased two to three times since then (21).

Applegate (1) asserts that Texas is representative of other States and that there are examples of ranchers in every State who lease hunting land. In Oregon, where public land is available for hunting, leasing arrangements on private ranches are increasing. In many areas of the West, though, the lands used for recreation are public lands. Income from hunting permits and tourism accrue to the States and local businesses, not to ranchers.

Nonforage Plant Products.—Uses and income derived from nonforage plant products are not well documented, but they are significant for certain users in certain areas. For example, seeds are harvested in some areas for range reseeding, mineland reclamation, and urban horticultural use (fig. 73). Some seeds may bring prices as high as $8/lb (12).

Pinyon pine nuts have been a staple food source for American Indians throughout the intermountain States. The few nuts reaching urban markets are prized, Potential exists for maximizing production of native stands and also harvesting nuts from areas unsuitable for any other crop. Some range plants have potential as biomass fuel sources (see ch. IX for a detailed discussion). Other potential plant products include wooden jewelry and fibers for basketry and paper. These activities will probably continue and may increase in the face of declining water supplies for other uses,

Nonmeat Animal Products.—The production of many nonmeat animal products, such as fur, wool, and hides, can increase substantially without seriously affecting water resources, Since most produced now are not sold, their sale would represent an increase in agronomic water-use efficiency. See the discussion on animal mixtures, below,

MULTIPLE-USE TECHNOLOGIES

The multiple-use concept has been instrumental in shaping technology development and adoption for rangelands, Two examples follow, one in which technology developed for the mining industry is moving into agriculture and one in which agricultural technology was refined by multiple-use demands,

Surface-Mined Land Reclamation

Introduction.— Mining activity is widespread on Western rangelands and on some crop and pasturelands. Coalfields in Montana, Wyoming, North Dakota, South Dakota, Utah, Colorado, New Mexico, and Arizona underlie more than 100 million acres. Approximately 90 additional minerals are found in sufficiently large deposits to be mined,

Mining activities influence water in many ways. Water that flows through a mining area may be degraded in water quality, a conse-

Figure 73.—Summary Information for Using Big Sagebrush in Rangeland Reclamation

Big Sagebrush *(Artemisia tridentata)*

Characteristics

Height:	1.5 to 9 ft (0.5 to 3 m)
Spread:	1 to 5 ft (0.3 to 1.5 m)
Growth form:	Round, generally erect, multi-branched, evergreen shrub
Root-system type:	Deep, spreading

Habitat

Distribution:	Nebraska to eastern California, south to New Mexico, Arizona
Elevation:	1,500 to 10,600 ft (495-3,500 m)
Topography:	Wide spread, low-elevation rangeland to mountain slopes
Salt tolerance:	Fair
Drought tolerance:	Good
Soil:	Fine- to coarse-textured, acidic and basic, moderate to deep, well drained

Use

Forage value:	Important for wildlife on winter rangeland
Erosion control:	Control mass-soil slippage
Landscaping:	Gray-green foliage

Propagation

Seed:	Good germination at room temperature but is speeded at cooler temperatures: seeds ripen late September
Vegetative:	Collect stem cuttings Feb. to April treat with 2.0°/0 IBA powder

SOURCE Institute for Land Rehabilitation, Select Ion, Propagation, and Field Establishment of Native Plant Species on Disturbed Arid Lands, Utah Agricultural Experiment Station Bulletin 500, 1979

quence of the mining process (ch. IV). Substantial water supplies may be required during mining operations and stream widening. Lake drainage, surface-flow diversions, streambank disruption, and ground water interference may all occur. Collectively, mining activities affect water supplies and the use of the land for agriculture.

Mining also has indirect effects on water use. Surface mining destroys existing natural communities completely and dramatically. Because water is the major factor in revegetating these areas, many reclamation efforts focus on water use and management.

Assessment.—Most arid and semiarid rangelands have not and will not face such drastic disturbances. Probably only a small percentage of all rangelands will be surface mined for coal. Yet water remains the key to maintaining or restoring rangeland productivity. As a result of these similarities, many reclamation technologies can be used directly on other rangelands. This is important because Congress has mandated improving the condition of the 160 million acres of public rangelands in the 17 Western States and recent legislation* established a national commitment to maintain and improve public and private rangelands, making them as productive as feasible for all rangeland values. Until now, such improvements were slow and few technologies existed.

Reclamation technologies are not expected to increase agronomic water-use efficiency of plants or animals greatly, but preliminary research suggests that some gains can be made (27). A variety of technologies are possible:

- water-retention methods to speed plant establishment and minimize runoff,
- plant breeding for hardy and palatable grasses,
- planting and seeding technology,
- soil building techniques, and

* Forest and Rangeland Renewable Resources Planning Act, (Public Law 93-378]; Public Rangelands Improvement Act, (Public Law 95-514).

- management of vegetation composition and ecosystem analysis.

Dryland sodding is an example of a technology to prevent erosion and to establish plant cover rapidly. With this technique, thickly cut native sods containing grasses, forbs, and shrubs are placed on steep, erosive slopes and special machines have been developed to handle native sod efficiently and effectively.

In the past, rangeland managers avoided the use of many potentially useful plant species on undisturbed lands owing to problems with seed size and shape, low germination, or seedling vigor. Because regulations require large proportions of native plants in reclaimed areas, new planting and seeding technology was stimulated. Special techniques and equipment now exist for harvesting, treating, and planting fuzzy, awned, sticky, minute, or otherwise troublesome seeds. In some cases, the vulnerable seed and seedling stages are protected by specially designed containers or underground stem and root transplants are used in revegetation efforts on marginal or "impossible" sites.

The productivity of some undisturbed range sites is limited by soil conditions—e. g., high sodium or clay content—that affect nutrient and water availability as well as toxicity to plants. Surface mining requires the complete reconstruction of soils. Therefore, reclamation research has stimulated the development of soil building technologies that have the potential for transfer to other lands. These include the use of biological, chemical (organic and inorganic), and physical amendments to the soil.

Most surface mining regulations have rigid requirements for determining the success of reclamation. In some cases, the composition of vegetation is specified. As a result, interest has increased in vegetation management methods as well as in long-term ecosystem analysis. Some management methods, such as rangeland fertilization, burning, irrigation, interseeding, and grazing, were developed for undisturbed rangelands but are being refined by reclamation efforts. Others, such as long-term analyses of plant/environment interactions, are seldom matched in duration or intensity by traditional rangeland research (25).

Legal, social, political, economic, and cultural factors may be barriers to implementation of reclamation technologies on undisturbed rangelands. For example, Federal law on the use of native plants and land with agricultural potential has affected State regulation and research. Schechter (24) maintains that R&D are inadequate and that capital does not exist to meet this need, A single discipline focus hinders application of the research that has been done. For example, undisturbed rangelands may contain more than 40 plant species, but revegetation efforts often focus on a single species. Moreover, there is a general lack of understanding of soil biota. More information about complex multiple species interactions is needed, a task requiring an interdisciplinary effort.

Economic return varies widely among Western agricultural land uses, making certain technologies suitable for some lands but not for others. For example, private companies may spend $2,500 to $6,000/acre to reclaim land that has been surface mined for coal (14). A nearby acre of undisturbed land may sell for $200. Clearly, reclamation is costly, even when disturbance is less drastic than that from surface mining. Improvement of unmined but degraded public rangelands using a variety of technologies would represent a major economic investment. The Bureau of Land Management has a backlog of $34.7 million in needed range improvements, and the cost of additional projects is estimated to be over $148 million (37).

Management of Undesirable Plants and Animals

Introduction. —Range managers identify a number of plants that decrease livestock forage or have other undesirable features. Some of these plants are not natives of the West but have spread after introduction from other parts of the world. Undesirable plants maybe highly adapted to arid and semiarid conditions and therefore difficult to remove once established.

Photo credit: USDA-Agricultural Research Service

The Range Improvement Machine is being developed by USDA/ARS in cooperation with Montana State University for use on semiarid rangelands and marginal pasturelands to increase grass and forage yields. It uses **a** packing wheel system. For purposes of water conservation, the gap in each wheel leaves a check dam at 7-ft intervals (inset)

The definition of plant pests depends on the intended land use and the specific site, but plants such as mesquite, oaks, and sagebrush are often considered to be undesirable by ranchers.

Human use of rangelands has exacerbated the increase of plants considered undesirable. Intensive grazing, the exclusion of fire, and temporary cultivation have changed the composition of plant communities. Invasion of woody species also decreases the availability of forage for livestock and is the primary cause of rangeland degradation. Therefore, technologies to control "brush" are one way to increase rangeland productivity. Usually, large amounts of water are not directly involved in these technologies. Instead, increases in productivity lead to higher water-use efficiencies. Other applications of these technologies may be made to increase water runoff specifically (ch. VI),

In some parts of the West, principally in public rangelands in Utah and Nevada, wild horse and burro populations also degrade lands. Experts estimate that 60,000 to 70,000 wild horses compact soils, overgraze plants, and generally interfere with careful rangeland management and optimal use of forage. Programs to control these and other animals are used to achieve three management objectives: 1) protect livestock, 2) reduce the number of herbivores that compete with livestock for available forage, and 3) protect the range from overgrazing and subsequent damage to productivity. Most control programs seek to optimize population size, not to eliminate all wild animals.

Assessment.—Studies of several plant species indicate that control or removal significantly increases soil water, resulting sometimes in a concomitant increase in available forage for livestock. However, not all stands of undesirable plants use large amounts of water that would be available to other users, and the amount of water affected depends on the original type of vegetation, its density, local precipitation, and the control method used. In some cases, vegetation considered by ranchers

Box Z.—Integrated Brush Management: A New Approach for Degraded Rangelands

In the last few years, emphasis in range management has shifted from eradication of noxious plants to their careful control by combinations of methods, known as integrated brush management, The basic principles include:

- reducing dependence on any single control method,
- using the synergistic effects from treatment combinations,
- increasing both livestock and wildlife habitat,
- developing flexible treatments for different conditions,
- integrating treatments with other management techniques, and
- enhancing economic returns from brush management.

These techniques are applicable to most sites, but to be successful they require long planning horizons: brush-management systems are designed to span 15 or 20 years. These program are expected to be adopted first in areas that have major brush problems. For the next decade, Texas, Oklahoma, and New Mexico will probably be most involved. Adoption could increase rapidly if costs of other range-management technologies or Federal constraints on herbicide use increase.

The costs of these techniques vary widely, and there are additional indirect costs and benefits. primary constraints to implementation are economic, especially for the first costly step in a sequence. Technical constraints are significant since research still is in the formative stage and treatment testing requires long time periods.

SOURCE U.S. Congress, Office of Technology Assessment. *Impacts of Technology on* U.S. Cropland *Rangeland* Productivity *(Washington, DC: US* Government Printing Office, OTA-F-166, August 1982) to be undesirable provides important benefits. For example, most stands of trees and shrubs furnish wildlife habitat. They may also provide shade for livestock, protect soil from wind or water erosion, increase water runoff for offsite uses, or contribute to the attractiveness and diversity of arid and semiarid lands.

Each of the common brush-control technologies has advantages and disadvantages. Mechanical control is labor- and energy-intensive and thus expensive. After chopping and clearing plants, some residue usually remains, which is advantageous, but considerable soil disturbance also occurs. Chemical control is specific, effective, and often less expensive, but some chemicals, improperly applied, may cause crop damage or health hazards. Regulations largely prohibit chemical use on Western Federal rangelands. In contrast, fire, always a feature of Western rangelands, is gaining acceptance as a major control technology. It is inexpensive, but all areas cannot support fires and the resultant denuded ground is subject to soil erosion.

These conventional control technologies have been criticized for being used without regard to their effects on values other than livestock production. Integrated brush management is a newer technology that has the potential for enhancing multiple-use values of rangelands. Some experts contend that this technology can make a large contribution to increased water availability for agriculture on rangelands,

With an integrated approach, it is possible to manage noxious plants for their potential

Photo credit: USDA-Soil Conservation Service

Fire is gaining acceptance as an effective brush-control technique. Here, junipers are ignited to increase forage production on rangeland in Arizona benefits. For example, because mesquite may form very dense stands, and cattle sometimes have difficulty digesting mesquite pods, mesquite is often considered to be noxious. But these trees have traditionally been used for food, forage, and firewood production by Southwestern Indians who considered mesquite's importance greater than that of corn and wheat. Unripened and ripened pods and seeds were eaten by humans and animals, and the wood continues to be prized. There is evidence that selected varieties of mesquite could become nitrogen-fixing, low water-using crops which require little or no tillage (11), Big sagebrush is also commonly regarded as a noxious plant because it is aggressive and unpalatable to domestic livestock. For these reasons it has been the target of widespread eradication programs. An alternative approach would be to use the richly variable germplasm base to improve the species' forage qualities.

An integrated management approach can also be used for noxious animals, but wild horse and burro control represents a particularly difficult problem. These animals are without effective predators and are capable of rapid population increases. They can inflict heavy damage on rangelands. Both offsite and onsite effects on water resources have been noted but never quantified (20). Transplanting animals is only a temporary solution, fertility-control with drugs is expensive, and selective killing is sometimes strongly opposed by the public.

Animal Mixtures on Rangelands

INTRODUCTION

Different animals have different food preferences, i.e, they consume different plant species, different parts of the same species, and the same plant parts growing at different heights. Therefore, mixtures of animals use resources more fully than any one species. When species more adapted to dry conditions are included, they may also use resources more sustainably.

ASSESSMENT

Some experts feel that animal productivity can be increased by stocking rangelands with more than one kind of animal (10). For example, new combinations of livestock and wildlife species could double range productivity in some areas, and an optimal grazing management scheme for shortgrass range sites might allocate forage to cattle (67 percent), bison (20 percent), sheep (12 percent), and antelope (1 percent) (17). Sheep and goats graze over wider areas and rougher terrain than do cattle, Used in combination, they could control brush and weed invasion resulting from overgrazing by cattle.

Few range managers have attempted operations of this complexity. Ranchers with private lands—e.g., in Texas—have the most experience with large mixtures of animal species. These mixtures usually include unusual exotic animals that are stocked for recreational hunting or photo safaris, not for large-scale meat production. This concept awaits full-scale testing with North American game and domestic animals.

Optimal combinations of herbivores can only be determined if the diet-selection process is understood. Currently, no models exist that can define this process and it is not possible to predict dietary or spatial use of any given site, The limited numbers of experiments with mixed-species grazing systems do not provide information on their long-term effects. For example, little is known about the effects of such systems on overall efficiency of energy use or of nutrient cycling. Furthermore, little is known about the effects of larger numbers of sheep on populations of big game animals.

When more than one species of animal grazes an area, it is critical to match demand to available vegetation. Overlapping plant preferences could destroy a plant species before the process is apparent in declining animal health or numbers. Innovative approaches are needed to study the responses of mixed animal

Box AA.-Alternative Agriculture in Arid/Semiarid Lands: The Innovators

It maybe **decades** before alternative agriculture is practiced widely in arid and semiarid lands. Pioneers are at work now, and it may be their work that shapes the future of American agriculture.

Workers at the Land Institute in Salina, Kans., are developing a grain-producing system that mimics the diverse and productive grasslands which once flourished on the Great Plains. They use perennial plants to decrease tillage and erosion; legumes and quickly decomposing composites to cut fertilizer needs; and unusual germplasm to increase nutrition and seed yield.

Cooperative studies between botanists at the Arizona-Sonora Desert Museum (Tucson, Ariz.) and the University of Arizona explore the potential for crop mixtures of short-lived desert plants and perennials. Native plants such as mesquite, tepary beans, gourds, devil's claw, and cacti are blended with biological technologies for fertilization, pollination, and soil-water absorption.

The Agroecology Program at the University of California, Santa Cruz, focuses on research and small-scale field trials of new systems. Experiments include ones on integrated pest management, pollination, multiple cropping, the use of fire in agriculture, trees as crops, farm pond aquaculture, and comporting. Part of this program is tailored to students, but it also includes cooperative projects with local farmers and extension agents.

Rodale Press has been a leader in the alternative agriculture movement and, with the establishment of the Rodale Research Center, it produces careful and credible agronomic research. This center, especially through its work with grain amaranth, is now working more with crops for dry lands. A new consulting role in foreign arid lands can be expected to strengthen these aspects of its program.

species on different types of range sites, especially where sustained productivity of wild and domestic species is the goal.

The combination of domestic livestock—e,g., sheep and goats with cattle—has not been practiced extensively, The sheep and goat industries are both relatively small, providing a limited market for new technologies and constraining innovation, The sheep industry, after a sharp decline due to low returns, high labor requirements, and losses to predators, seems to be at the beginning of a modest recovery owing to increasing competitiveness of natural fibers. Both sheep and goat producers face strict regulations that favor cattle producers,

Alternative Agriculture

INTRODUCTION

The predominant agricultural systems used in the arid and semiarid parts of the United States represent a fraction of the kinds of systems available worldwide. Present systems are largely based on frequent tillage; the use of a few, very specialized, annual crops; and additions of large amounts of added synthetic fertilizers and pesticides. While these systems predominate, some Western farmers do not use them.

Some farmers and ranchers are experimenting with types of agriculture that are quite different. These new systems are diverse and may include complex mixtures of crops in one field (polyculture or intercropping); they may include perennial grains or tree crops instead of annuals such as corn, sorghum, and wheat (perennial polyculture or permaculture); or they may eliminate synthetic pesticides and commercial fertilizers (organic farming), Generally, they rely heavily on natural biological processes, such as nitrogen fixation by legumes, instead of artificial replacements, like fertilizers (table 81),

ASSESSMENT

Such alternative agricultural systems have demonstrated their usefulness under certain conditions. Some scientists observe their in-

Table 81 .—Examples of Human Substitutions for Biological Processes

Biological process displaced	Non biological process substituted
Natural fertilization in plants/seed dispersal	Plant breeding/harvesting of seeds
Fixation of atmospheric N by bacteria	Application of artificial nitrogenous fertilizers
Exploration of soil by roots for potash and phosphorus and water	Application of artificial fertilizers; irrigation
Natural control of pests and weeds	Use of pesticides and herbicides
Collection of feed by animals	Harvesting, processing and automated provision of compounded feed; forage conservation
Grazing	Zero-grazing (the cutting and carting of herbage)
Natural deposition of excreta on the land	Collection of excreta from housed animals and its disposal, treatment or distribution on land
Incubation of eggs by hen birds	Artificial incubator
Natural service by male animal	Artificial insemination
Natural hormonal processes	Control of light, day-length and temperature; use of synthetic hormones
Natural suckling (of calves and lambs)	Artificial rearing on milk substitutes
Natural immunity to disease in animals	Use of vaccines
Use of animal power	Use of machines and fossil fuel

SOURCE C R W Spedding J M Walsingham and A M Hoxey. Biological Efficiency in Agriculture (London, U K Academic Press, 1981)

creasing credibility and expect that they will assume greater importance in the future (23). The advantages claimed for these systems are many and include lower use of expensive, fossil fuel-based chemicals that may be hazardous to human health and the environment, improved soil structure and better growing conditions for plants, less soil erosion, a more diversified and therefore more stable agricultural base, more nutritious agricultural products, and more efficient use of natural resources.

Some of these claims have been substantiate]. For example, farms producing a variety of products generally reduce their risks and increase the effective use of total resources. Polycultures of plants grown together, in contrast to monoculture of one plant, may use soil nutrients more efficiently, increase economic returns, improve the nitrogen status of crops when legumes are part of the mixture, and provide stability of yields over time (16). Systems that eliminate synthetic chemicals also eliminate the possibility of pesticide contamination and minimize contamination of ground water and runoff from commercial fertilizers (21). Organic farming has been shown to increase wildlife populations and in at least one Western State, the U.S. Fish and Wildlife Service recommends it for producing crops for wildlife (29). Other claims, such as the effects of organic farming on crop nutrition, are less well understood and many need further research.

The earliest advocates of these technologies based their arguments on ideological grounds or on the perception of severe environmental problems resulting from traditional agricultural practices, More recent practitioners are adopting alternative systems on economic grounds, For example, most of the cornbelt/Great Plains organic farmers surveyed by Strange (29) cited the importance of lower production costs and insulation from rising variable input costs, One-fourth of these farmers borrow no operating capital. Many of these people also share a belief that farmers and ranchers should not exhaust the natural resources on which the future of agriculture depends. For this reason, they feel that alternative agricultural systems are among the most forward-looking and resource-conserving of technologies under development.

Both basic and applied research on alternative systems have been limited. This research is not simple: controlled experimentation is difficult, no one type of alternative agriculture is representative, and the benefits claimed to accrue may take decades to manifest themselves. Public and private investment in research is small. For example, USDA formally decided to terminate research in this area contrary to the results of its own study (35), Interested farmers have had few places to get information. One survey of organic farmers showed that only 5 percent sought or received help from land grant universities and only 3 percent could find assistance from extension agents (29). A more extensive foreign data base exists for some technologies, such as the polycultures of India, France, and Africa, but this information generally has not been adapted for use in the United States.

Research is lacking also on alternative systems for arid and semiarid lands, For example, most research on organic farming has been done in humid regions of the United States. Polyculture systems, such as those extensively used in India, are more common in arid regions and they generally perform better in dry seasons. But claims that polycultures use water more efficiently or are able to tap water unavailable to monoculture have not been substantiated. For these reasons, it is impossible to predict under what site-specific circumstances polyculture will prove to be advantageous.

This lack of information has contributed to an absence of organizations to assist producers with questions and problems related to alternative agriculture. The people who are interested in many of these systems generally are not part of the traditional agricultural community and are not well organized among themselves. Therefore, knowledge of alternative agricultural systems has had limited acceptability and visibility. There is evidence that the tendency to dismiss new systems as impractical or bizarre may be declining. For example, under a congressional mandate*, USDA completed its first study of organic farming in 1980, and the University of Nebraska holds an annual organic farming field day. Large numbers of farmers continue to express their interest in alternative methods despite the lack of official encouragement.

It is not clear yet to what extent these technologies will be applicable to farms or ranches of varying sizes and in different geographic locations. Most of these systems are highly integrated and require good management skills, substantial knowledge about plants and animals, and marketing expertise. The need for these skills may place low limits on the size and scale of a particular enterprise. While the productivity of some farming systems maybe high per unit of land, the labor intensiveness may make productivity per farmer or rancher relatively low.

There is no consensus whether these systems would produce, in the near term, yields as large as those currently achieved. For example, some experts feel that the widescale adoption of organic farming would result in lower, but acceptable, total productivity (4). Other results indicate that adoption of organic farming practices might actually increase farm unit production by decreasing operating costs. The greatest benefit of these systems is in sustaining or improving inherent land productivity, This benefit could compensate for short-term yield reductions if they materialized (33).

Multiple Use of Croplands

INTRODUCTION

Rangeland uses for recreation and wildlife are important adjuncts to meat production in many areas. Similar multiple uses of cropland are possible, and some farmers are actively pursuing this option. In fruit, nut, and vegetable growing areas, some farmers invite customers to pick their own produce. Farmers may provide other services, such as hayrides to fields or samples of processed produce. Management of some areas emphasizes, for the visitor, the recreational aspect of the visit,

Grain-growing areas provide important wildlife habitats and some States allow leasing them for hunting. In Texas and California especially, irrigation and cultivation practices can sometimes be managed to increase wildlife habitat. The large pheasant and waterfowl populations that often result provide an opportunity for farmers to lease land at attractive prices.

'Section 1461 of Title XIV of the Food and Agriculture Act of 1977 (Public Law 95-113).

ASSESSMENT

It is difficult to assess either the present or potential role of multiple uses of cropland. No central source of information exists on these land uses. For some areas, though, it is clear that wildlife and hunting uses of cropland are having a large economic impact.

Wildlife in many areas have suffered from recent agricultural practices. Fencerow-to-fencerow cultivation, removal of grain stubble, intense grazing of pastures, and extensive weed and pest control have adversely affected wildlife. These practices partly reflect the drive for higher agricultural production and partly the feeling that wildlife is a farm liability. Thus in some areas, recreational use of cropland is unlikely in the face of negative attitudes. Hunting on croplands is also limited by farm schedules. Hunting season may occur during harvest or other busy times when it is not practical to have visitors in the fields.

In other areas, agricultural practices have enhanced wildlife, and farmers have welcomed and used this increase (table 82). In South Dakota, small-game hunters purchase a $5 wildlife stamp in addition to their hunting licenses. The revenues generated are then paid to landowners for the maintenance of pheasant nesting cover. More than $500,000 was paid in 1979 to farmers at an average rate of $22/acre. After 5 years in operation, 535 landowners are involved and about 15,000 acres of cropland have been diverted for wildlife purposes (l). Some wildlife species do not benefit from such programs: in areas in which land conversion among rangeland, cropland, and pastures occurs, only those animals adapted to changeable conditions are favored,

Table 82.—Gross Revenue to Western States[a] From Hunting and Fishing Licenses in 1981

State	Hunting licenses ($)	Fishing licenses ($)
Arizona	—	3,585,167
California	7,005,827	24,156,555
Colorado	18,370,746	5,436,643
Idaho	5,322,771	3,100,745
Montana	4,688,759	3,797,090
Oklahoma	4,564,625	4,144,402
Oregon	7,543,558	6,408,517
Texas	6,314,663	7,406,271
Utah	5,598,120	5,129,323
Washington	5,867,014	6,704,656
Wyoming	10,919,365	—

aStates included rank among the top 25 in the United States in terms of State revenue from these activities

SOURCE U S Department of Agriculture, Soil Conservation Service *Texas Conservation Tips*, December 1982

Set-aside programs for wildlife are expensive to the organizers and may not encourage wide participation. The multiple use of farmland, therefore, depends on strong economic incentives for individual farmers. This is the case when croplands are leased for hunting. In Texas, for example, farmers are being encouraged to consider pheasants as a cash crop and to plan management decisions to accommodate gamebirds. By planting wheat, sorghum, and corn to provide cover and food in proximity to water, farmers can enhance pheasant production. Ponds that capture irrigation water runoff also have become prime pheasant habitat where farmers can encourage the growth of important gamebird vegetation. During hunting season, these practices translate into leases to individual hunters or sports clubs at a minimal cost of $25/person/day or $125/person for the season's opening weekend (28).

In Texas and other States where irrigation has changed the face of agriculture, the availability of water supplies may determine the future of both agriculture and wildlife. Changing water use in the Central Valley of California has had major effects on wildlife and has made hunting an important use of irrigated land. In many cases, the changes in in wildlife habitat or populations inadvertently accompanied changes in agricultural technology.

Table 83 shows some of the more general interactions between technological changes and resources in the Sacramento Basin of California. Specific changes may also be traced. In fewer than 100 years, about 5 million acres in the Central Valley were converted from grasslands, marshlands, and waterways to high-value farmland and urban areas. As a result, a number of species of waterfowl have become dependent on cultivated cereal crops, whereas other species dependent on the natural vegetation have declined. Pastures and fields of corn, rice, mile, wheat, and barley provide habitat for large numbers of migratory and resident

Table 83.— Relationships Between Agriculture Practices and Fish and Wildlife, Sacramento Basin and Delta-Central Sierra Hydrologic Study Areas

Practice	Opportunity for water saving	Agricultural viewpoint: Positive	Agricultural viewpoint: Negative	Fish-wildlife-recreation viewpoint: Positive	Fish-wildlife-recreation viewpoint: Negative	Comments
Increase ground water pumpage	Possibly very large	Farmers gain operating independence and dry-year flexibility	High initial cost; big energy user	Reduces diversions from river	May increase percolation	One of two true means of saving water in basins
Increase reservoir storage	Moderately large	Increased dry-year supply	None	Decreases peak flows; increases dry-year summer flows; enhances reservoir-type fisheries	Would flood out native lands	Opportunity for true in-basin water savings
Reduce water applied to rice	Large, possibly several hundred thousand acre-feet	Should produce a **large** net saving in applied water use; save energy and fertility	Would increase irrigation management costs; increase TDS of drainage water	Would tend to reduce diversions from the Sacramento River, leaving more water for in-channel use	Would decrease drain flows, hence diminish riparian vegetation and fish flows, increase TDS and water temperatures	No savings would result unless storage provided
Level all rice paddies, form rectangles	Included above	Would decrease applied water use by an estimated 5%; increase yield, reduce water management and harvest costs, increase net profit	Would take land out of production for one crop year; require capital outlay	Included above	Elimination of berms would reduce wildlife habitat	Now catching on rapidly in rice-growing areas
Drain wet mountain meadows; improve water management	Small	Would reduce water use; increase forage production	Would require annual maintenance cost; high original investment	None	Would reduce wetland habitat reduce late summer downstream flows	As time goes on, practice will be employed through the incentive to increase forage production
District practices; canal lining (reduce seepage); increased use of relift pumps, control ditch bank vegetation, clear channels	Large, could reduce district demands	These practices will decrease water demands on a district basis; could increase yields and decrease fertilizer needs	Would require more energy, capital, and manpower, increase the unit cost of water, leave drain water users with no available supply	None	Would reduce wetland habitat. reduce fish flows, raise water temperatures, increase TDS, concentrate pesticides, and increase channel velocities in some areas	Must develop incentives for districts to take action; must persuade people that water-saving practices are necessary

SOURCE State of California, Department of Water Resources Bulletin No 198, May 1976 waterfowl. In some parts of the valley, farmers can realize significant economic returns from leasing hunting rights. These farmers may flood cornfields and create wetlands instead of planting a second crop to increase waterfowl populations, In some cases, this practice also removes salts that have built up in the soil from previous irrigations. A large number of duck clubs now makes use of these croplands. For example, at least 84 private duck clubs exist in San Joaquin County, Calif., and about one-third, or 12,000 acres, of the land leased for hunting represents flooded fields.

In other areas, irrigation water is becoming less available, and careful management is undertaken. For example, where rice is grown, land leveling—the use of fewer levees between fields—and more productive rice varieties have increased yields but decreased both cover and food for wildlife. In these areas, wildlife populations have declined. Some experts feel that the situation is becoming critical. Greater pressures for careful irrigation management are driving farmers to use less water, and they cannot be expected to continue to sustain large water-dependent wildlife populations.

Computers and Information Management

Introduction

Ranchers and farmers manage information daily, Decisions regarding which crop to plant or when to sell livestock, for example, are based on obtaining and evaluating information from a variety of sources. The availability of electronic computers has changed the nature of information management, and computers are rapidly becoming everyday tools in agriculture.

Agricultural scientists have used computers for research analyses for some time. The direct availability of computer-assisted analysis to ranchers and farmers is more recent. Computers are having an impact in two different ways:

1, university/State extension services are providing access to large, shared computing facilities through networks of terminals; and
2. producers are purchasing microcomputers for home use.

The large computer systems share central data storage and processing facilities. The Agricultural Computer Network (AGNET) is a good example. AGNET was developed by University of Nebraska scientists in the 1970's and expanded into five Western States on a pilot basis in *1977.* As of 1980, six States are full partners in the operational system: Montana, Nebraska, North Dakota, South Dakota, Washington, and Wyoming. AGNET relies on a large central computer in Nebraska and the backup skills of nearly 20 computer specialists in the participating States. Extension Service offices and individual users gain access via local terminals to program libraries. These terminals can be as simple as touch-tone telephones or as elaborate as nonportable terminals with video screens and printer attachments.

AGNET was designed to be a tool for making farm and ranch management decisions and for providing up-to-the-minute market news and extension information. Over **200** agricultural programs are available now to users and it is considered to be the best system available to farmers and ranchers today. Programs include ones for cattle production, tax planning, machinery costs, home food preservation, irrigation scheduling, and soil loss. Farmers and ranchers are often included in planning these programs to ensure their usefulness.

Microcomputers (also called home or personal computers) can provide some of the same facilities. These units often have a keyboard, a video or television screen, magnetic data and program disks and disk drives, and a printer. They are self-contained and often users rely on programs developed for their particular machine. Farmers and ranchers use these small systems for business accounting as well as for storing and analyzing records of herd performance. Some microcomputers have graphics programs for displaying the results of analyses, Telephone couplers allow microcomputers to be used as terminals and provide access to the large computer systems.

Assessment

Some experts predict that computers will become commonplace during the 1980's and that the farmers and ranchers who do not use these management tools will be out of business by 1990. Computers make recordkeeping more precise and can help prevent management errors. Both of these elements are crucial when profit margins are low and prices fluctuate widely.

Farmers and ranchers with timely access to large systems such as AGNET can use elaborate computer technology at minimum personal cost. They can use tools that were specifically designed for agriculture and many that were tailored to conditions in the West.

Costs for direct terminals into large systems such as AGNET vary from minimal monthly telephone rental charges to $7,000 for the most elaborate purchased ones, Several small portable terminals cost about $1,500. Also, users pay long distance charges for the time during which the computer link is actually made. These charges may increase operating costs beyond the initial purchase price of the microcomputer. Purchase and operating costs are usually borne by universities and cooperative extension services in order to make terminals available in county offices and for specialists to use for local demonstrations, Some extension offices supplement large computer systems with microcomputers and are developing special agricultural programs for them. For example, Utah State University is developing irrigation programs for their Apple microcomputers.

Agriculturists who rely on their own microcomputers will have fewer tools with agricultural applications immediately available. Telephone couplers into the larger systems are probably necessary to have adequate agricultural programs. Such linkages provide the best of the small and large systems, but they are far from routine now. Microcomputers that are sufficient for agricultural applications cost $4,000 to $5,000 for the machinery, or hardware, and an additional $2,000 to $3,000 for programs, or software. The more elaborate and expensive microcomputers also are more flexible, They are faster and easier to use, and their standard features allow hardware and software "extras" to be exchanged among different brands,

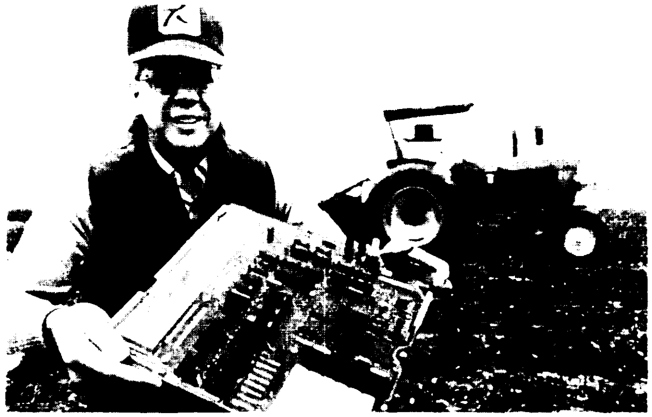

Photo credit: USDA-Agricultural Research Service

Replacing the driver? Agricultural engineer Robert Schafer presents tomorrow's farmers with the circuit board from a computerized guidance system for tractors and other farm machinery, Research shows that computer-controlled traffic across croplands can reduce soil compaction considerably

The trend to greater reliance on computers in agriculture has begun despite the substantial costs involved, A number of vital institutional issues remain to be resolved, including: 1) the role of the Federal Government in technology R&D, 2) the role of Federal and State agencies in training, and 3) the need for improved cooperation among various agencies. These issues may redefine the role of the Cooperative Extension Service, alter the audience which it serves, and determine how widely Government-developed computer technology is distributed. For example, some experts think that some extension services lag behind vocational schools and even behind some high schools in providing computer training.

Will Western agriculture participate fully in the computer "revolution?" The technology is available, but evidence suggests that Western farmers and ranchers have trailed Midwesterners in its adoption, perhaps by as much as 10 years (15). It is clear that some computer applications can contribute to greater efficiency of water use, But computers can also be used as irrelevant and expensive toys; such uses will not necessarily help solve difficult water problems.

CONCLUSIONS

Agricultural management technologies that affect water supplies in the arid and semiarid region represent a wide combination of individual practices, including animal and plant management, irrigation water management, cultivation practices, and computer and information management. Each of these management technologies is used in recognition that water is part of the natural system in which it is impossible to affect any part without affecting another.

Management technologies have high potential for maximizing production from available water, plant, land, and animal resources in the arid and semiarid region. Their application and significance in the future will depend to a great extent on research efforts by the scientific community, on economic costs and benefits of application, on managerial abilities of producers, and on decisions by policy makers at the local, State, and Federal levels.

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