PROGRESSIVE AGRICULTURE IN ARIZONA

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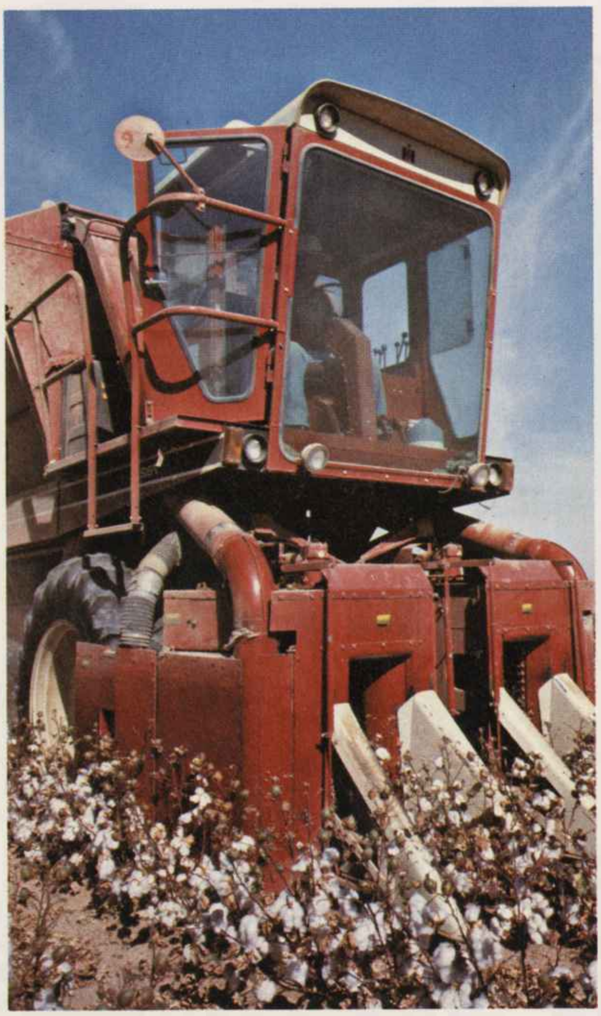

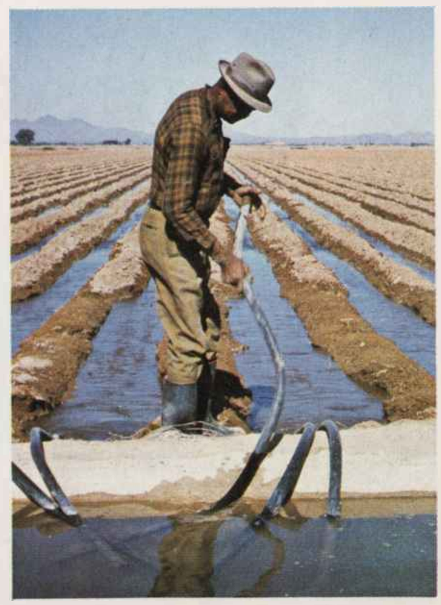

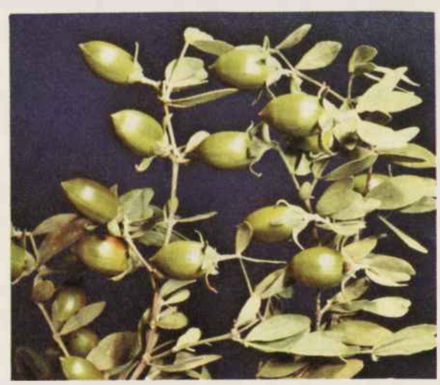

Special Issue:

The Future of Agriculture in Arizona

PROGRESSIVE AGRICULTURE IN ARIZONA

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Special Issue:

The Future of Agriculture in Arizona

Published quarterly by the College of Agriculture, including the Schools of Home Economics and Renewable Natural Resources, the Agricultural Experiment Station, Cooperative Extension Service, and Resident Instruction at The University of Arizona, Tucson, Arizona 85721. Bartley P. Cardon, Dean.

Guy W. Webster, Editor, Hector Gonzalez, Graphic Artist.

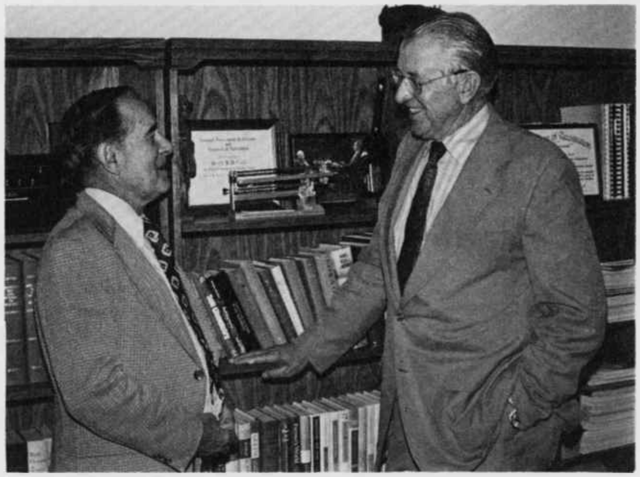
Letter from the Dean

So many factors will shape the future of crop agriculture in Arizona that quantitative predictions are unwise. However, historical trends and current developments give some clues about the next few decades.

As our water supply becomes more restricted by law and by cost, agriculture can maintain its present place in the state's economy only by continuing to increase the efficiency of water use and by concentrating on crop and livestock enterprises that give high net returns. This can be done. The state's productivity, already among the highest in the world per acre, theoretically can continue to increase. Our agricultural exports can continue to help meet the food and fiber needs of the world while strengthening the country's foreign-exchange status.

The degree to which these possibilities are fulfilled depends in part on continuing strength in research and development, and in implementing beneficial innovations. Maintaining financial support for agricultural education, research and extension will be necessary. Given that support, some more specific predictions are reasonable. Increasingly sophisticated management techniques will be required for successful growing of crops in the state. Computers will help growers keep detailed records and make decisions throughout the growing season, such as when and how much water to apply. Integrated pest management, now in its infancy, will become standard practice in the future. As farm laborers become better organized, farm managers will become more proficient and knowledgeable in labor relations. Many of Arizona's successful farm operators and managers are UA College of Agriculture graduates. The future need for sophisticated management skills will continue to improve farm equipment, chemical tools and crop varieties.

Other public policy decisions besides the level of support for research and education will have great impact on agriculture in the state. Some social planners would use agriculture as a tool for social change and redistribution of wealth, overlooking agriculture's function of producing food and fiber for people's basic needs. Outdated concepts of family farms are one symptom of this confusion. Future trends in the costs of energy and credit will affect agriculture more than many other industries. So will developments in the interpretation and possible modification of the state's 1980 Groundwater Management Act.



Deans Darrel S. Metcalfe and Bartley P. Cardon.

Many of these factors are unknown quantities. One important player in the future of Arizona agriculture is now a known quantity, an encouraging one. As of December 1, Dr. Bartley P. Cardon will have succeeded me as dean of the UA College of Agriculture. He is a graduate and former faculty member of the college who, for the last 25 years, has managed the growth and success of a large feeds company. Arizonans in both plant and animal agriculture know Dr. Cardon well. So do agricultural leaders around the country and the world with whom he has worked and consulted. These people know that Arizona is fortunate to have a man of Dr. Cardon's knowledge and abilities leading the efforts of the College of Agriculture.

Darrel S. Metcalfe

Darrel S. Metcalfe
College of Agriculture
The University of Arizona

Introduction

Arizona is threatened with a polarization of interests that could impede rational solving of serious state issues. The problem centers on the use of water for crops and the public perception of the need for that use. Reasonable and unreasonable claims and questions have been aired. The intent of this issue of *Progressive Agriculture in Arizona* is to examine agriculture in Arizona in terms of its value to the state, nation, and world, to discuss its problems, and to suggest possible solutions.

Agriculture is an important source of income for the state. Depending on the year, it ranks second to fourth in cash receipts for the state. Income is about equally divided between animal and plant agriculture, with the combined total cash receipts reaching $1.7 billion in 1979. While animal agriculture has problems, many of them related to problems in plant agriculture, this issue of *Progressive Agriculture* focuses only on plant agriculture.

Let's face it: plant agriculture would not exist in Arizona as currently practiced without supplemental water. We have mined our underground water, causing water tables to drop in many areas. The 1980 groundwater law is a direct result of concern about the long-term effect of continuing depletion of underground water.

Farmers' production costs have climbed spectacularly in recent years. Agriculture is as seriously hit by rising energy costs as any private home or car owner. Interest rates have pushed up investment costs, too. With public misunderstanding added to this list of woes, the Arizona farmer of today might well be tempted to quit. And yet, never has there been a greater need for solutions. It is important that Arizona solve its crop production problems in a way that continues agricultural income to the state and food and fiber production for the nation. What happens here soon can happen later elsewhere in this nation and abroad where groundwater is used faster than it is replaced. Solving Arizona's water problems while maintaining crop production will point the way for other areas.

Agricultural research and the dissemination of useful findings to producers have helped make this country the best-fed in the world with the lowest fraction of disposable income spent for food. Our system of research and extension has been widely copied in other countries.

We look to the future. The maximum benefit from agricultural research occurs, on the average, seven years after discovery and loses its major benefit within 13 years. However, some discoveries are accepted rapidly. Discoveries such as Pima Cotton, steam-rolled grain and insect-resistant varieties of alfalfa have had immediate, dramatic impacts on Arizona agriculture. On the other hand, decade-old research on minimum tillage is just now making a significant impact and decreasing the energy used to produce crops.

We can solve our problems if we pull together. Polarization will solve nothing. Collectively, we can grow useful agricultural products in Arizona and bring the state into a water balance at the same time.

L. W. Dewhirst, Director
Arizona Agricultural Experiment Station

Many Harvests from Arizona Crops

Arizona's irrigated fields are among the most productive agricultural lands in the world.

In upland cotton and in alfalfa, the state's two biggest crops by acreage, Arizona yields per acre are double the national average and higher than any other state's. Durum wheat is another major Arizona crop when the price is up, as it is this year and was in 1976. Yields per acre here are two and one-half times the national average (see Table 1).

Climate is one reason for the state's high yields. Southern Arizona, with most of the state's cropland, gets sunshine for 85 to 90 percent of the possible hours per year, more than anywhere else in the country except adjacent parts of California. Crop plants turn that direct sunshine into useful products. The growing season lasts almost year round in the agricultural areas of Maricopa, Pinal and Yuma counties. That has given farmers valuable flexibility in timing the use of their fields. Reliable irrigation, coupled with low rainfall, has provided them with valuable control over water.

Another factor in our high productivity is the rate at which Arizona farmers adopt advances in productive practices and crop varieties. Compared to farms elsewhere, Arizona farms are large in acreage and income. Per-farm net income in Arizona averaged $36,907 annually from 1968 to 1978. That was the highest in the country and more than 30 percent higher than the second-highest state average. Their large scale helps Arizona farms afford the investments necessary to keep at the forefront of agricultural technology.

Less than one out of 50 acres of Arizona is farmed. In some crops, though, the state ranks high in total production as well as in

Table 1.
Yields per acre: Arizona and U.S. average.*

Crop	Arizona	U.S.	Ariz. rank among states
Upland Cotton	1,008 pounds	497 pounds	1
Alfalfa Hay	6.4 tons	3.1 tons	1
Durum Wheat	72.1 bushels	29.1 bushels	2

*Figures are averages of 1977, 1978 and 1979 harvests.

yield per acre. It is among the top five states for production of cotton, vegetables, citrus fruits and grapes (see Table 2).

Table 2

Value of Production, Arizona and U.S.
(In $1,000,000s of 1978 production)

Crop	Ariz.	U.S.	Ariz. percent of U.S. total	Ariz. rank among states
Upland Cotton	297.3	3,022.0	9.8	4
Pima Cotton	23.7	41.8	56.7	1
Vegetables	130.5	3,636.1	3.6	4
All Hay	82.9	6,579.7	1.3	28
All Citrus	45.8	1,592.7	2.9	3
All Wheat	28.3	5,280.5	0.5	20
Sorghum	15.0	1,444.5	1.0	11
Corn	14.4	14,889.0	0.1	32
Grapes	13.5	997.2	1.4	5
Barley	6.0	843.6	0.7	15

Prices and Supply

How does this productivity affect Arizona consumers?

National and international marketing patterns dominate the modern food and fiber industries. This means that, except for a few products, changes elsewhere influence consumer prices in Arizona more than local changes in production and demand do. How close a supermarket is to the farm that produced the food on the shelves has less effect on consumers' prices than it did in years past. Prices for more heavily processed products, such as bread or cotton jeans, are even further insulated from such geographical effects. Transportation costs have not climbed high enough to change this picture much yet, but could encourage more localized marketing in the future.

Conversely, the same marketing patterns that make local agriculture's effects less deep also make those effects broader. Arizona does its share in stabilizing the supply and prices of agricultural products nationwide and in contributing to the national balance of trade. The state's unique growing conditions help some farmers grow products that fit into specific niches in the American food supply, most notably off-season vegetables. For crops grown in other states, too, the variety of production areas helps offset poor years in one area or another. A long heat wave parched much Texas cotton this year, for example. The price rise that resulted would likely have been significantly higher if Arizona cotton were not available.

Besides helping to supply food and fiber for the state, the country and the world, Arizona agriculture provides jobs and other economic benefits.

Jobs and Income

Cash receipts for Arizona agricultural products in 1979 totaled $1.7 billion. More than half of that, $905 million, was for crops, rather than for livestock and animal products. Even after adjustment for inflation, cash receipts for Arizona crops have climbed 27 percent in the past decade.

The people who benefit economically from this level of production can be grouped into three categories: those with direct farm jobs or income, those with other jobs or income related to agriculture in the state, and the general public.

In 1979, 28,000 people worked on Arizona farms and ranches. This included 16,000 who were farm operators or members of their families, and 12,000 who were hired workers. The hired workers earned an average of $3.42 per hour. The operators and families figure includes only those household members who worked 15 hours or more per week without receiving cash wages.

Total personal income for Arizonans working in agriculture has averaged $369 million annually for the past three years. Figure 1 shows agricultural income in relation to other income sources. In rural communities, the dependence upon agriculture is much higher.

Some of the non-farm income in the state does come from the production inputs sold to farms, such as machinery, credit and supplies, and from the processing and selling of agricultural products. Arizona agricultural producers spent about $1.2 billion on production expenses in 1978. A large but unmeasured share of these costs was paid to Arizonans in non-farm jobs.

Many of the jobs in food and fiber industries, such as in grocery wholesaling and retailing, would exist whether farm products were grown in Arizona or elsewhere. The number of Arizona jobs related specifically to Arizona farm products has not been calculated. Products grown here also become the raw materials for related jobs in other states and countries.

Processors and first handlers added 25 percent to the value of Arizona agricultural products in 1975. This group includes meat processors, cotton ginners, canners, and workers in harvesting, sorting and packing where farm employees do not perform these tasks. It does not include grocery wholesalers or retailers. For just crops, excluding animal products, these types of workers added $184 million in value, or 32 percent, to the $567 million that farmers were paid for their crops that year.

Figure 1. Major sources of Arizona personal income (in millions of dollars). The total is $13.25 billion.

Figures are averages of 1977, 1978 and 1979 incomes. Source: U.S. Department of Commerce, *Survey of Current Business.*

Important Exports

Besides the Arizonans whose incomes depend directly or indirectly on agriculture, the whole population gains some economic benefits from the strength of agriculture in the state. A chief benefit is the large contribution of Arizona agriculture to the net export balance of the United States in agricultural commodities. This contributes greatly to the strength of the dollar in international exchange, which makes it easier for U.S. consumers to buy foreign-made goods at lower prices and in the process achieve higher standards of living.

From the 1920s into the 1960s, the U.S. capability of producing more food and fiber than the nation consumed was primarily a problem of managing the surplus to protect farmers. That situation has changed dramatically with increasing worldwide demand. Now, that extra production capacity is the United States' best lever against a weak dollar that would aggravate the problem of costly petroleum imports. In fiscal 1980, the agricultural trade surplus of $23 billion cut the non-agricultural trade deficit of $51 billion down to a net deficit of $28 billion.

Key Arizona crops, including cotton and wheat, are among the U.S. crops exported in large quantity. Thirty-nine percent of U.S. cotton is exported, including 90 percent of Arizona-grown cotton. Twenty percent of Arizona lemons were exported over a recent five-year period.

Property taxes are another way agriculture benefits the general public. In 1978, property taxes on Arizona farms totaled $28 million. The benefits that farms gain from the taxing jurisdictions must be subtracted from that figure to show the net benefit to the non-farm public.

Cotton's Role

As Table 2 shows, cotton's importance tops that of other Arizona crops in value of production and share of total U.S. production as well as in acreage. Cotton has high value per acre, so it can pay for the high costs of irrigation and pest control necessary for production in Arizona.

Table 3

Cotton Production in Arizona

Years	Ariz. & U.S. production	Rank among states	Cotton as % Ariz. irrigated crops
1935-39	1.6	13	33.4
1945-49	2.3	13	28.3
1951-53	5.8	6	54.6
1955-59	5.8	5	31.6
1965-69	5.9	5	24.8
1975-79	8.7	4	35.7

Table 3 traces the historical growth of the Arizona cotton industry. The jump in the early 1950s resulted from high prices and the dropping of acreage limits set by federal price-support programs. The acreage limits were restored after the Korean War, but have had virtually no impact since the early 1970s. Exports support cotton prices now. In 1979 and 1980, cotton acreage again passed 600 million. In the period from 1975 to 1979, cotton represented 42 percent of the value of Arizona's total crop production.

Vegetables are another high-value crop, but their prices fluctuate more rapidly and more widely than cotton prices. This higher risk factor demands that vegetable growers have the capital strength to withstand bad seasons. High-value tree and vine crops also require capital and 1980, cotton acreage again passed 600 thousand. In the period from 1975 to 1979, cotton represented 42 percent of the value of Arizona's total crop production.

Many of the lower-value crops shown in Table 4, including small grains, sorghum, safflower and sugarbeets, are often grown in rotation or double-crop systems with cotton. Crops that might not return the full costs of production can be profitable when the grower's fixed costs, such as machinery and real estate, are already covered by another crop.

Alfalfa is sometimes rotated with cotton, too. As a multi-year crop, however, it must bear fixed costs of production for itself. The rotation aids in pest and disease control and soil fertility.

Table 5 shows the geographical patterns of irrigated agriculture in Arizona. Recent acreage gains have been on Indian reservations, along the Colorado River and in groundwater pumping areas in western Maricopa and in Cochise and Graham counties.

Energy costs and state water allocations will probably minimize future establishment of any new groundwater-irrigated cropland. The same forces, plus urban growth, are also apt to stop irrigation pumps on some existing cropland. On the other hand, for the rest of this cen-

Table 4

Thousands of Acres of Selected Crops Planted in Arizona 1935-1979

	1935-39	1945-49	1951-53†	1955-59	1965-69	1975-79
All Cotton	212	240	652	377	292	491
All Wheat	43	29	20	82	49	227
Sorghum	39	72	49	159	219	98
Barley	59	164	153	193	173	58
Corn	37	32	35	40	31	52
All Hay*	214	273	244	265	235	246
Vegetables**		93	88	95	92	66
Safflower*					36	14
Citrus (bearing acreage)	18	19	17	15	30	55
Sugarbeets***					22	15

† Korean War years.
* Acres harvested.
** Broccoli, cabbage, melons, carrots, celery, cauliflower, lettuce, onions, potatoes; first column includes 1946-1949 only.
*** First column includes 1967-1969 only.

Source: Arizona Crop and Livestock Reporting Service.

tury, surface water from the Central Arizona Project (CAP) and along the Colorado may be turned to use on new acres of cropland. The CAP will provide less water for agriculture than was planned a decade or two ago, and the water will be much more expensive than other surface water already used for irrigation. Current plans, however, may allow new land to be irrigated economically on Indian reservations in Pima and Pinal counties. Further than 20 years ahead, it is harder to predict that new acreage can continue to offset retired cropland.

Table 5

Number of Acres of Irrigated Crops Grown in Arizona in Thousands of Acres

	Apache	Cochise	Coconino	Gila	Graham	Greenlee	Maricopa	Mohave	Navajo	Pima	Pinal	Santa Cruz	Yavapai	Yuma	State Total
1935-39	10	8	2	2	34	6	355	2	7	23	110	3	9	62	634
1945-49	13	20	3	*	35	6	424	*	9	28	216	*	11	85	849
1951-53	16	47	13	*	37	6	544	*	15	56	297	6	14	148	1195
1955-59	11	83	4	1	36	6	493	6	12	56	283	7	17	181	1194
1965-69	8	106	8	1	56	6	477	6	17	51	227	3	8	207	1179
1975-79	8	132	2	1	60	5	490	11	15	48	268	3	7	310	1359

* Not available.

Challenges and Responses

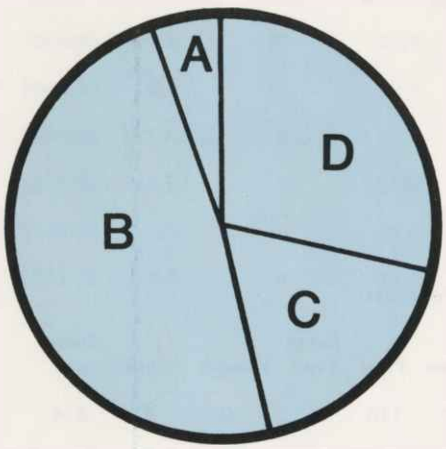


Figure 2. Arizona's water supply in thousands of acre-feet.

A. Natural Recharge 300 — Groundwater 2,500
B. Overdraft 2,200

C. Colorado River 900 — Surface water 2,300
D. Other 1,400

Normalized 1970 conditions.
Total: 4,800,000 acre-feet. An additional 3,500,000 are diverted or pumped, but return to the water supply instead of being depleted by use.

Source: Arizona Water Commission.

Limits to amounts of water and good land challenge Arizona agriculture. The past and predictable growth of the state's population increase the demand for these resources. Energy costs are also pushing up the price for pumping groundwater.

Of the two, water is a more critical resource for our agriculture than land. For Arizona land to be good cropland, it needs a supply of irrigation water. However, high water costs are putting some irrigated cropland out of production, and urban growth is overrunning some of the remaining cropland that gets the less expensive irrigation from rivers and lakes, instead of from underground. Soil quality factors are also important.

Agriculture is adapting to the limits and costs of available water. The problems appear soluble by individual adoption of techniques already available or under development. The loss of prime cropland converted to other uses is a longer-range issue. It may require a collective approach, rather than individual efforts, to give due weight to society's present and future interests.

The Problem: Water

About 80 million acre-feet of precipitation fall on Arizona in an average year. (Each acre-foot equals 43,560 cubic feet.) Of that water, plus some that drains into the Colorado River from other states, about 3 million acre-feet are diverted from rivers and lakes for use by people in Arizona. In addition, almost 5 million acre-feet of water are pumped out of the ground each year. About a third of the water pumped or diverted flows or seeps back into the water supply. Actual depletion, based on 1970 conditions, is estimated at 4.8 million acre-feet. This includes 2.3 million acre-feet from surface water and 2.5 million from groundwater. The state's underground supplies of water are replenished naturally with only about 300,000 acre-feet a year, so roughly 2.2 million acre-feet of pumped groundwater are not replaced (see Figure 2).

We are overdrawing our groundwater account by about 2.2 million acre-feet annually. Consequently, underground water levels are dropping in many areas. Near Stanfield and Eloy, levels have dropped about 180 feet since 1940. Water that is further underground is more expensive to pump out, and often higher in unwanted salt content. In several places, such as an area near Picacho, the ground itself is subsiding as water is sucked out from under it. Some evidence suggests the subsiding began even before local pumping began, though it has been greatly accelerated by the pumping.

To stop the overdraft on groundwater reserves, Arizona must reduce pumping by about 2.5 million acre-feet a year while the population continues to increase rapidly. Irrigated agriculture uses nine-tenths of the water used in the state, counting both surface and groundwater. The other tenth goes to homes, mines, industries, electric power, and fish and wildlife uses (see Figure 3).

Room for improved efficiency exists for all types of water users. Phoenix residents, for example, use one-third more water per person per year than Tucson residents. However, the biggest share of the necessary reduction in water use will come from the biggest user, irrigated agriculture. Cutting back the amount of water pumped for irrigation will mean either less irrigated land or less water per acre.

Two attacks underway against the overdraft problem are the Central Arizona Project (CAP) and the 1980 Groundwater Management Act. CAP aims to substitute surface water from the Colorado River for some of the groundwater used. By current estimates, the project will deliver 1.5 million acre-feet in 1990, tapering off to 1.0 million acre feet by 2030. The new groundwater law requires the management of pumping, with quantity restrictions phased in over the next 45 years in specified "Active Management Areas."

A more immediate factor fostering conservation in groundwater use is the high cost of pumping. Just in the past five years, escalating energy costs have pushed pumping costs up 50 to 65 percent in major groundwater irrigation areas of Maricopa, Cochise and Pima counties. Long-term cost arrangements in Pinal County electric districts have held costs per foot of lift steadier in that county, but many of those arrangements will be renegotiated by 1990.

In addition to the energy-price factor, dropping water levels also raise pumping costs. Two consecutive years with above-average precipitation have actually raised water levels in some areas, especially near the Gila River at Painted Rock Reservoir and downstream. In most pumping areas, though, and over the longer time-frame, groundwater levels are dropping.

For many farmers who use groundwater, water costs amount to half or more of their total variable costs. Figure 4 shows the recent increases in this proportion of costs for some crops.

Prices received for major crops have increased in recent years, too, offsetting some of the water-cost inflation. Nevertheless, the higher pumping costs have raised the incentive for efficiency in irrigation: each acre-foot that is not pumped because it is not needed represents more dollars saved than it used to. An acre-foot worth of new efficiency in irrigation does not, however, reduce groundwater overdraft by the same amount. Some of the water now lost in irrigating a field flows or seeps back to a surface or underground water supply. Thus, even substantial improvements in irrigation efficiency will not solve overdraft problems.

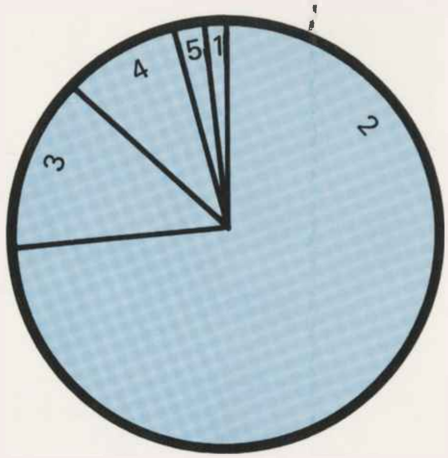


Figure 3. Annual water use by Arizona's major water users (in thousands of acre-feet of water depleted).

1. Steam-Electric Power 20
2. Irrigation 4,294
3. Municipal & Industrial 329
4. Mining 131
5. Fish & Wildlife 40

Normalized 1970 conditions.
Source: Arizona Water Commission.

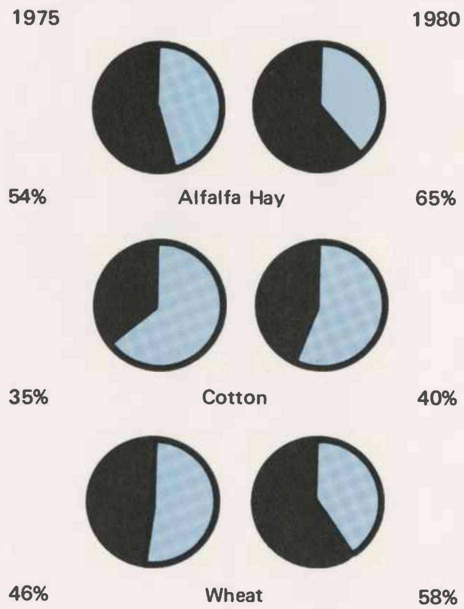


Figure 4. Water as a percentage of total variable production costs of selected Arizona crops, 1975 and 1980.

Figures are based on variable water costs ($44.54 for energy and $5.40 for repairs per acre foot) and total variable costs of production for selected crops in the Queen Creek area.

The Problems: Land

Nationwide, an average of four square miles of prime farmland have been converted to non-agricultural uses each day for more than a decade. In Arizona, the total amount of cropland has stayed close to 1.2 million acres for 30 years. The stability of the total, however, masks local patterns of change. Between 1967 and 1977, an average of 32,000 acres per year of Arizona agricultural land were converted to urban, built-up, rural transportation or open-water uses. Ten thousand of these 32,000 acres per year were prime farmland before conversion. While land in some areas has changed from cropland to other uses, however, new cropland has been claimed from the desert in other areas.

Some previously farmed areas, especially in Pinal County, have been idled because rising costs for water and other production factors have made farming uneconomical in those spots. This type of change is reversible, should future market conditions make agricultural use of the land attractive again.

Other losses of farmland are less reversible. In Pima County, more than 10,000 acres of formerly irrigated farmland near Tucson have been retired from production because the city bought the land for the water rights that come with it. This sort of land-use change is determined not by whether crops can be raised economically on the irrigated land, but by whether urban users or agricultural users are willing to pay more for the water rights. The 1980 Groundwater Management Act provides for the purchase and retirement of some irrigated lands starting in 2006, and for other types of water-right transfers to non-agricultural uses starting immediately.

Even more permanent are the changes of land from farm use to residential and industrial uses as Arizona's cities expand. In a single 10-month sample period eight years ago, 3,650 acres in a one-million-acre study area in and around Phoenix changed from farm use to urban use. More than 80 percent of the lost farmland had Class One soils, the top rating from the U.S. Soil Conservation Service. Another study included one million acres that ringed the Phoenix urban area in 1970. More than 65,000 of the 375,000 acres of agricultural land in that area in 1970 had changed to residential and other urban uses by 1978 (see Figure 5). Some prime cropland that was northwest of the Tucson urban area a decade ago has also become part of the city.

As described in the preceding article, new agricultural areas have been opened or expanded as farmland around the cities disappears. Many of the new areas, though, especially in western Maricopa County and in Cochise and Graham counties, depend on groundwater rather than on the less-expensive and usually less-salty surface water available to much of the land that has gone out of farm use near Phoenix. In Yuma County, most of the new agricultural land gets irrigation water from Colorado River projects.

The land around the cities is in an assortment of low-intensity uses, including parks, rangeland, mines and undeveloped desert, as well as cropland that varies in quality. Arizona cities are going to keep growing rapidly. The challenge is to weigh society's long-term interests into the decisions about which parcels of low-intensity land will be converted to urban uses. Poorly planned urban growth may bequeath to future generations an undesirable quantity, quality or distribution of farmland. The public interest in a potential for increased agricultural

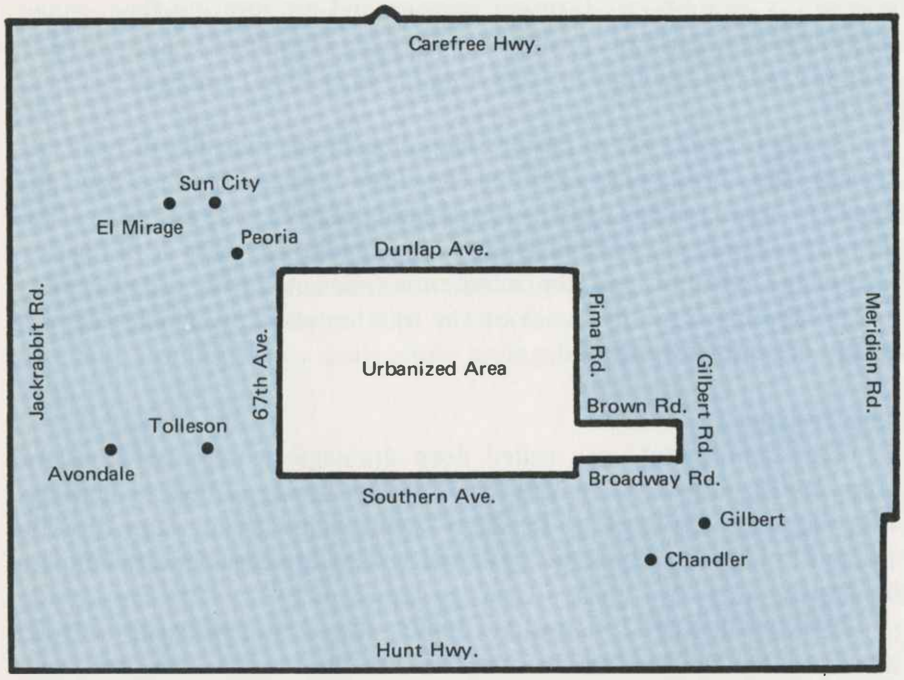


Figure 5. Generalized 1,600-square-mile rural-urban fringe study area in Maricopa County (shaded area) in which 18 percent of the agricultural land in 1970 had been converted for residential and urban uses by 1978. From "A Directed Graph Approach to Rural-Urban Fringeland Conversion," by George F. Hepner, 1979.

production in the future is not built into current systems for buying and selling land around cities.

Possible Responses: Water

Efficiency in irrigation means applying only as much water as a crop really needs. Efforts to achieve that in Arizona date back hundreds of years, but have recently expanded in urgency and scope. Irrigation as we now know it developed in an era when energy costs were relatively modest. Interest in water-use efficiency was mostly academic, since paying for an extra irrigation or two made more economic sense than risking a yield-reducing water stress. The new energy costs and overdraft problem are now restoring water to a major place in economic calculations. Yields per unit of water applied and per unit of energy are as meaningful as yields per acre. The successful irrigator in Arizona's future will quote yields per acre-foot as readily as he now quotes yields per acre.

Optimum efficiency in irrigation will require management tailored to the soil and climatic characteristics of each field, rather than treatment as though all were identical. This management will require more precise measurement of the characteristics of each acre. Fortunately, the tools for this job already exist.

Plants use water, plus carbon dioxide from the air, to make simple carbohydrates, which are both the fuel and a basic component for growth of the plant. Four other things can happen to water that is applied to a field: runoff, deep seepage, evaporation from the soil and transpiration from the plant. Each of these four components of the "field water budget" offers opportunity for improving irrigation efficiency. Even before the irrigation water reaches the field, though,

Table 6

A Comparison of Improved Irrigation Systems

Side-roll Sprinkler System

Efficiency:	70-80 percent
Capital Requirement:	$200-$300 per acre
Labor Requirement:	moderate
Energy Requirement:	moderate to high
Soil Requirement:	no special conditions
Restrictions:	best for shorter crops (alfalfa & grain), poor in windy conditions

Center Pivot

Efficiency:	70-80 percent
Capital Requirement:	$275-$325 per acre
Labor Requirement:	low
Energy Requirement:	moderate to high
Soil Requirement:	sandy or high-infiltration-rate
Restrictions:	special practices required for trees and vines; less affected by wind than other types of sprinklers
Machine Operations:	some problem due to circular field

(continued on page 13)

some water can be lost through seepage and evaporation from canals and reservoirs.

Runoff

Runoff results when water is applied faster than it can infiltrate into the soil. This component of the field water budget has been the easiest to measure and usually the easiest to reduce or eliminate. The capture and reuse of runoff water from the tail end of irrigation furrows is a common practice on Arizona fields. Adoption of such practices to eliminate runoff losses on the fraction of farms which have not already done so is warranted.

Deep Seepage

This component, also called deep drainage or percolation, is the water which moves down out of the root zone, pulled by gravity. It is the most difficult of the four components to measure directly but also holds the opportunity for the largest increases in efficiency in the future.

Non-uniform infiltration is a major reason for seepage losses. In furrow or flood irrigation, the amount of water that soaks into any part of the field depends on the length of time that water is ponded on the surface at that spot. In order for high spots to get enough water, low spots must get too much water. In a poorly leveled field, this can mean as much as 40 percent too much water is applied overall. Even on precisely leveled fields, though, variations in the permeability of the soil in different parts of the field can cause non-uniform infiltration of water. Soil permeability can vary several-fold within a single field.

The use of laser equipment to level fields precisely is spreading rapidly. This technique solves the problem of high and low spots on zero-slope fields. Conventional land grading usually is adequate for sloped fields, where tolerances are greater. No amount of leveling can overcome the problem of permeability differences, however. To reduce that problem, control of water infiltration must be removed from the soil surface and incorporated into the irrigation system. Sprinkler, trickle and related systems can apply the desired quantity of water more uniformly over the field. Trickle systems can raise irrigation efficiency to 80 to 90 percent. Sprinklers, or well-graded furrow systems that catch and re-use runoff water, can achieve 75 to 80 percent efficiency. Fifty to 70 percent is estimated for a poorly graded furrow or flood system without a re-use feature and with irrigation practices geared to convenience of labor. The more efficient systems, however, are also more expensive initial investments (see Table 6).

Since virtually all irrigation waters in the West contain salts, some deep seepage is essential to prevent salt build-up in the root zone. In most cases, leaching with about one-tenth of the applied water, once a year, is sufficient to maintain a favorable salt balance. Again, uniformity of application is important, since the portions of a field most in need of leaching are those that normally get the least irrigation water.

Excessive preplant irrigation and poor irrigation scheduling can also cause excess deep seepage. Efficient irrigators can assess the amount of water the soil in each field can hold against the pull of gravity and then apply as nearly that amount as possible. A flow meter at the pump can aid in the accuracy of application. Neutron moisture probes, available to farmers through irrigation consultants, can detect deep seepage. Checking each field periodically with a neutron probe helps refine estimates of how much water the soil can hold in the root zone.

For efficiency, irrigation scheduling must be extremely flexible. Irrigation by the calendar will eventually become obsolete. Irrigation for 24-hour periods in order to save labor will also disappear. Farmers may monitor their soil moisture, estimate the time and amount of their next irrigation from weather data, and apply precisely the amount required. Automatic systems with pre-programmed micro-processors to start and stop the flow may allow savings in pump energy-use and in labor.

Evaporation

Runoff and deep drainage usually find their way back to the surface or groundwater system, but evaporation from soil and transpiration from plants are lost into the atmosphere. These last two components are difficult to measure separately. They are often considered together as "consumptive use" or "evapotranspiration." Great strides in understanding and accurately estimating them have been made in the past 20 years.

Evaporation from the soil is greatest when the soil is wettest. Some modest savings in water loss are possible by reducing the percentage of soil wetted, as with trickle irrigation. Trickle systems, however, keep the wet portion of the surface wet longer than other systems do. Shading the surface with a mulch or with early vegetative cover can reduce evaporation losses. Narrower row spacings can result in an earlier complete vegetative cover. As water-use efficiency becomes a more important factor in comparison with the advantages of standardized farm machinery, experimentation with row spacing and plant density is increasing. Precise timing of preplant irrigations may cut evaporation losses, too. If a preplant irrigation is applied too long before planting, much water may evaporate or seep away before the seedlings can use it.

Transpiration

Transpiration gets the most attention of the four components in the field water budget. However, much of the optimism about increasing irrigation efficiency by reducing transpiration losses is based on misconceptions. Reducing transpiration from a given plant reduces the plant's total dry-matter yield proportionally. Most of the water transpired from a plant exits through small openings, called stomates, in the leaf. The stomates must open up to take in carbon dioxide from the atmosphere for photosynthesis, and this permits the transpiration of water vapor.

The water-use efficiency for a crop plant is the amount of yield the plant produces with a given amount of water. When yield is considered as the total dry-matter production of the plant, the efficiency depends on two factors: 1) the difference between the water-vapor pressure in the leaf and the water-vapor pressure in the adjacent air, and 2) an efficiency factor for the type of plant. This basic plant factor is the same for all plants with the same type of photosynthesis. Crop plants fall into two groups, with the tropical grasses such as corn and sorghum being about twice as efficient as the others.

Table 6
(continued)

Trickle Irrigation System

Field Preparation: install pipes, emitters and porous tubes

Efficiency:	80-90 percent
Capital Requirement:	$650 and up per acre
Labor Requirement:	low to high
Energy Requirement:	low to moderate
Soil Requirement:	no special conditions
Restrictions:	crop must have high value to support debt service
Machinery Operations:	may have considerable problems due to tubes

Improved Furrow Irrigation System

Field Preparation: grade to uniform slope, install tailwater recovery system

Efficiency:	60-70 percent
Capital Requirement:	$65-$175 per acre
Labor Requirement:	moderate
Energy Requirement:	low
Soil Requirement:	uniform, with moderate slopes and low-to-moderate infiltration

Level Basin System

Field Preparation: laser-level and border, install water turnouts in concrete ditches

Efficiency:	80 percent
Capital Requirement:	$400-$900 per acre
Labor Requirement:	low
Energy Requirement:	low
Soil Requirement:	uniform soil of zero slope with moderate-to-low infiltration

For plants with the same type of photosynthesis, growing at the same place and time, less transpiration means less dry-matter production. Except for a few species that can open their stomates at night and store carbon dioxide until daylight, desert plants seem to use water for dry-matter production no more efficiently than traditional crop plants. Instead, they are able to grow more slowly, or grow only when water becomes available. It is unlikely that plant breeders, at least in the near future, will be able to produce plants for which the basic efficiency factor is substantially higher. Improvements can be expected to continue, however, in manipulating the distribution of dry matter among the various parts of the plant. For most crops, one part of the plant, such as the seed, the leaf, or the root, holds the chief economic value of the plant.

The difference in water-vapor pressure between the leaf and air can also be manipulated to reduce transpiration losses. The warmer the leaf, the higher the vapor pressure in the leaf. The drier the air, the lower the vapor pressure in the air. Thus, transpiration rates are high in warm, dry Arizona. Growing crops during the cooler seasons instead of summer can minimize transpiration losses here. In mid-summer, a daily water use of 0.4 inch is not unreasonable for a full-cover crop. In mid-winter, it might use 0.15 inch per day.

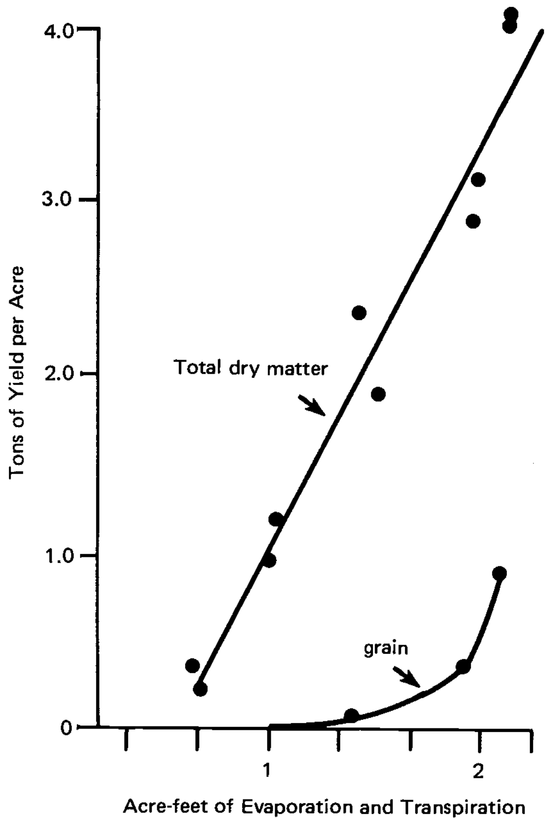


Figure 6. Production of corn grain and dry-matter with different levels of evapotranspiration, Yuma 1975.

Putting Theory to Work

Figure 6 illustrates the tie between evapotranspiration and yield. This information from a Yuma experiment includes both evaporation and transpiration. It gives dry-matter and grain yields for corn, but represents a pattern that holds for other crops as well. Between about eight inches and 26 inches of water use, each additional inch resulted in an increase of about 800 pounds per acre of dry matter produced. These numbers, but not the linear pattern, would be different for other climates or times of year. The upper end of the graph approaches the limit of evapotranspiration. Beyond that, additional water becomes runoff or deep drainage and does not increase yield.

Other factors, such as infertile soil, environmental stress or disease, may limit yield before the point of maximum transpiration is reached. For water-use efficiency, irrigation should be cut back when factors other than water limit growth. In such a case, soil water measurements are the best guide for irrigation management.

Figure 6 shows a second important point. Water use is closely related to dry matter yield. With alfalfa, the farmer cares about total dry matter, including the root system, but with many other crops, he is interested in just part of the plant, such as the grain or fiber. This harvestable yield is not always related simply to transpiration. Water stress often affects one part of a plant differently than other parts. For example, with decreasing water use in the 24 to 26-inch range, the grain yield in Figure 8 drops more sharply than the total dry-matter yield. Sugar beets are an opposite case: water stress may reduce total dry-matter yield without hurting sugar yield, unless the stress is extreme. Stressing cotton just prior to harvest reduces yields somewhat, but it is not possible to predict just how much yield reduction results from each inch of water withheld. Timing of water, as well as amount, can be important. Water stress at a crucial stage such as flowering or fruiting may be more damaging than stress at other times.

Consumptive Use vs. Water Duty

Consumptive water use for a crop is the amount of water evaporated or transpired during the growing season for that crop, when it is grown for maximum harvestable yield. The consumptive-use estimate presumes that plants are not subjected to water stress unless that is a deliberate and normal field practice for the crop. Table 7 gives representative consumptive-use amounts for some Arizona crops.

The new Groundwater Act requires the director of the State Water Resources Department to determine the "irrigation water duty" for farms. The duty is the amount of water reasonably required to irrigate crops historically grown on the farm. The water duty is not the same as consumptive use for crops grown on the farm. It is premature to speculate exactly how water duties will be set, but reasonable to expect that the considerations involved will include all four components in the field water budget discussed above: runoff, deep drainage, evaporation and transpiration. Once the water duty is set, the grower can use these same factors in determining how to use his limited water most effectively.

The Groundwater Act establishes five management periods for Active Management Areas. During the first, 1980-1990, water duties will be based on assumptions that lined ditches, tailwater pump-back systems, land leveling and efficient application practices will be used. The law does not, however, require a change from flood irrigation to drip or sprinkle systems. For the second management period, 1990-2000, the water duties will assume "maximum conservation," taking into account the costs of efficient systems. Practices that maximize deep percolation and evaporation losses through uniform application will be encouraged by the lowered water duties. Crops historically grown on a given farm will still be permitted there in the third management period, 2000-2010, when practices will be similar to those in the second but more stringent.

Some irrigators may find that pumping costs dictate even more water conservation than that mandated by law. An acre-foot of water pumped unnecessarily may make the difference between profit and loss when pumping costs approach $100 per acre foot. Growers will also be using the flexibility the law gives each irrigator to bank or borrow up to half of each year's water duty.

The law requires installation of a water-measuring device on each well pumping 35 or more gallons per minute in Active Management Areas and Irrigation Non-Expansion Areas. This responsibility may seem onerous to irrigators and will take some care to ensure that each gauge measures accurately, but careful measurement of the water applied to each field is the necessary first step in full mangement of water. Only when the grower knows, for his own farm, how much water is consumptively used and how much is lost to deep drainage can he maximize his yield per unit of water. The Arizona farmer of the future will keep water accounts as carefully as he now keeps financial accounts.

It is apparent that the amount of Arizona land in urban uses will continue to increase, and that barriers to groundwater pumping will make establishment of new irrigated areas increasingly difficult after the first years of the Central Arizona Project. Given these conditions, should public policy encourage the preservation of specific areas of top-quality cropland?

Table 7

Some Reported Consumptive Use Data for Arizona Crops*

Crop	Seasonal water use (inches)
Cotton	41
Barley	25
Cantaloupe	19
Sugar Beets	43
Potatoes	24
Wheat	23
Sorghum	25
Bermuda Lawn (April-October)	44
Alfalfa	74
Grapefruit	48

* Consumptive water use figures from Mesa, except grapefruits, from Yuma.

Level, well-drained land accessible to transportation networks is highly desirable for both cropland and urban development. Concern about how land should be allocated between these two types of use focuses on the difference between immediate advantages and future advantages.

Any public program to influence land-use decisions works against the assumption that free-market forces allocate land in a way that maximizes overall net benefits. A weakness of the land market working by itself is that it does not give full weight to the interests of future generations. Changes from cropland to city land are practically irreversible, so such changes limit the land-use possibilities available in the future. An allocation that gives maximum social net benefits now may leave future generations fewer acres, or lower quality, of cropland than would be most beneficial at that time.

Future interests can be protected by a public policy to conserve prime farmland through government action. But such action should only follow a realistic assessment of the free market's inefficiencies and inequities in allocating land compared to those possible under the proposed government action.

Various methods for conserving prime farmland are being tried in different states. In 1967, Arizona began a program of preferential tax assessment to protect land in low-intensity uses from property tax increases due to nearby urban growth. Farmland is taxed on the basis of its value in agricultural production instead of its market value as a potential site for housing or other high-intensity use. This approach has apparently not controlled the conversion of prime farmland to urban uses. It still allows sale of farmland to developers at market price. Careful empirical studies found that an even stronger California law, which prevents market-price sales of land taxed as agricultural, has been ineffective in slowing conversion.

New York has adopted an agricultural-district system under which a group of local farmland owners with combined property of more than 500 acres can agree to restrict use of their land to agriculture in return for property tax relief. Hawaii has developed statewide zoning. All land is zoned into four categories: urban, rural, agricultural and conservation. Connecticut is pioneering a system that compensates farmland owners for foregoing rights to develop or sell their land for more intensive uses. The government takes away development rights for the farmland it wants conserved and gives the farm owner development rights to other land where development is allowed. Anyone who wants to develop that land for intensive use must own the development rights as well as the land.

The fairness and effectiveness of these various programs are being evaluated in the states involved. University of Arizona agricultural economists are carefully studying land-use trends around Arizona cities. These types of information, coupled with extensive public participation, can help realize land-use allocations that are efficient and equitable for present and future generations.

Traditional Crops

Crop production in Arizona gives some of the highest yields in the world. Abundant sunshine, productive soils and the long growing season make this possible; the use of adapted crop varieties, tested production practices and effective pest control makes it happen. Water from irrigation instead of precipitation adds to the farmer's control over growing conditions, but also adds to his costs. The high production costs in the state increase the motivation to get top yields for maximum profit.

For decades, research has innovated production practices, and growers have adapted them, adopted them and added their own ideas. The Cooperative Extension Service has helped innovations spread quickly. So have market pressures: high yields are essential to Arizona growers because of the high cost of inputs. Our agriculture is energy-intensive, especially where it uses pumped groundwater, so inflation in energy hits hard.

Successful crop production in Arizona is a high-technology endeavor. The advancing sophistication that has kept Arizona growers at the forefront of scientific crop management can continue to keep agriculture strong here in the future. This continuing pattern of development also provides leadership for effective crop production in other irrigated arid lands around the world.

The needs of Americans and other people for farm products require that farmlands here and around the world maintain or increase productivity. In addition, Arizona lands offer unique products such as high-quality planting seed, extra long staple cotton, and fresh vegetables produced at times of the year when they are difficult to produce elsewhere in the country.

The stories of specific crops illustrate the advances being made in crop production technology in Arizona.

Cotton

In recent years, cotton has been grown on about half of Arizona's irrigated farmland (see Table 4, page 7). About nine-tenths of it is upland cotton. The rest is higher-value Pima cotton. The most successful growers start with one of the adapted and highly improved cotton varieties, carefully prepare a first-class seed bed, use high-quality planting seed and plant to a stand. They follow a strong pest-control program starting with preplant weed control techniques and often use systemic insecticides. They infuse water and nutrients based on careful monitoring and late season inputs based on the nature of the season. Picking is prompt. Essential to all of these steps are daily monitoring by an experienced manager capable of making on-the-spot decisions, the use of special resource personnel, and planning for the years ahead through use of improved field layout, crop rotations and manure.

Arizona's cotton yields per acre, double the national average, have changed little in the past 25 years. Advances in production techniques have focused on controlling the input costs. Current research points toward a shorter season and added efficiencies, especially in pest control and water use.

Several lines of research aim at making short-season cotton more profitable. Stopping cotton growth early and harvesting by September 15 can reduce water use by six to 12 inches per acre compared to current practices. The short-season system also eliminates three to five insecticide applications and sharply reduces overwintering populations of pink bollworm and tobacco budworm, the crop's most damaging pests. Short-season practices already can be seriously considered for about 10 percent of the Arizona crop. The major obstacle is that cotton profitability jumps when favorable late-season growing conditions occur and are turned to an advantage.

Two factors are likely to accelerate the shift to short-season cotton in coming years: One is that researchers are improving production methods for short-season cotton and breeding improved short-season varieties. Progress in the development of hybrid cottons makes successes in the breeding work likely. The second factor favoring a shorter season is that costs of late-season inputs are apt to escalate faster than the value of added late-season yields.

Short-season cotton also brings the prospect of planting cotton as a double-crop following small grains, lettuce, sugarbeets or other crops. This would add to the efficiencies because cotton's strong taproot can reach residual soil moisture and nutrients that have moved below the root zone of the winter crop, and because fixed costs such as land and some machinery can be spread over two crops instead of one.

The types of irrigation efficiencies described in the preceding article can be applied to many crops, but cotton's high acreage makes it the most important crop in total savings possible. For a 650,000-acre cotton crop, it is estimated that 400,000 acres could benefit from improved field layout to shorten the runs of water or from improved leveling, or both. While no specific figures are available, these physical improvements to fields may increase irrigation efficiency by up to one acre-foot of water per acre of cotton. Sprinkler irrigation systems have immediate-use prospects for cotton. Drip or trickle systems, though they offer even greater efficiency of water application, are still uneconomical due to their high initial costs.

Small Grains

Arizona wheat and barley growers have fine-tuned their production system, shifting in the past decade from grain types destined for animal feeds to those used for human consumption. This has been made possible by the introductions of short-strawed desert durum wheats and high-quality bread wheats that are highly productive, responsive to management and exportable at a good profit margin. While barley is more salt-tolerant and fits a special place in many rotations, its acreage dropped steadily in the 1970s.

The durum wheats require careful management of nitrogen and water inputs in order to produce top quality food grain. Specific requirements depend on soil type, and guidelines for decision-making have been based on research. Efficient production makes use of an adapted variety responsive to management and early planting at low rates to minimize fertilizer needs. Traditional spring wheats are grown as winter wheats at the lower elevations of Arizona. Growing them when temperatures are cooler makes water use more efficient by avoiding much of the summer period of high evaporation losses.

Development of a fully compatible rotation system for small grains and cotton for use on an every-year basis would rank as a major breakthrough for Arizona farmers. The Arizona Agricultural Experiment Station is near that goal in its small-grain research program. What is needed is a small-grain variety which can grow between cotton harvesting and cotton planting time and which can produce economically on low inputs. Years of breeding have produced Barley Selection E-5. It fits these needs closely enough to indicate they can be met fully in the foreseeable future.

Barley Selection E-5, grown without added nitrogen and with only 13 inches of added water, yielded 30 percent more grain in one test than popular varieties Gus and Arivat grown under the same conditions. The test variety also matured a full week before the conventional ones. That 30 percent difference amounted to 1,082 pounds of barley per acre. At about six cents per pound for barley, that would make E-5 worth $65 more than the older varieties for each acre grown under those low-input conditions. The goal is a barley for double cropping with cotton. Even at this stage of research, that $65 per acre for just one-tenth of a 650,000-acre state cotton crop could represent $4 million for the growers, if other factors were unchanged.

Sorghum and Corn

Grain from sorghum has been well adapted for Arizona conditions and is an important local input for the feeding of cattle. Our total sorghum acreage has been giving way to the higher value cotton, but sorghum is still a key component of Arizona agriculture because of its drought-tolerance and its adaptability to soils that are marginal for other conventional crops. Yields on such marginal lands have shown a steady increase for three decades. This is due to the use of improved hybrids, effective weed control, proper fertilization and judicious use of water.

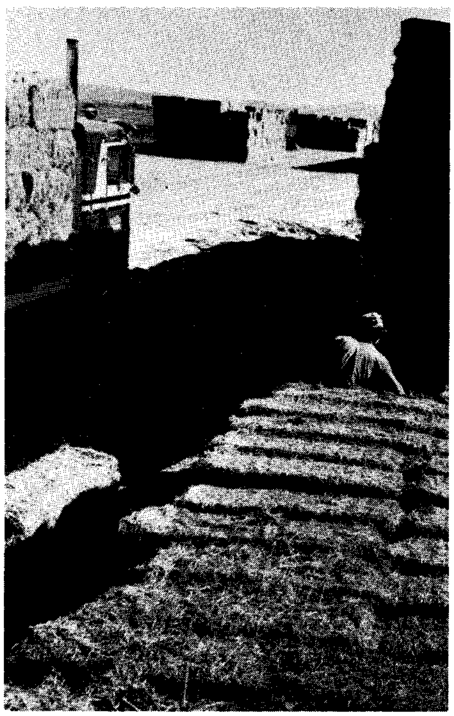
Continuing research is improving sorghum varieties and production practices for specific sections of Arizona. The Yuma area, for example, needs a summer crop to complement its winter crops. Sorghum may fill this need if improvements in disease resistance and stress tolerance are successful. Elsewhere, areas that get some rains in July, August and September may benefit from progress on a short-season, low-input sorghum variety. Improved selections using only one irrigation (at planting) have yielded 40 to 70 percent as much grain as fully irrigated varieties, depending on the amount of rain. This practice makes a crop possible where irrigation water is scarce or expensive.

Corn has adapted remarkably to the middle elevations of Arizona. Its new popularity among Cochise County farmers has tripled Arizona grain corn acreage since 1970. Principal factors in the success of corn production have been the introduction of locally adapted hybrids and the transfer and modification of sophisticated production technology from other areas where corn is grown. Especially important are the improved weed control and harvesting techniques. Narrow-row plantings, disease and insect resistant varieties, and proper fertilization and irrigation techniques have also been significant factors.

Alfalfa

Alfalfa's initial success in Arizona followed introduction of non-dormant varieties quite different from types grown in the Midwest. Its acreage in the state has stayed near 200,000 for 30 years, but yields have more than doubled during that time. Alfalfa is a key feed source for our dairy and beef cattle, horses, and other livestock. California dairies also use much Arizona alfalfa.

The alfalfa plant improves soil structure, aeration and drainage, and adds organic matter and nitrogen to the soil. The crop is favored for a rotation with cotton since cotton may produce an extra half bale or more per acre in the first year following alfalfa.



Arizona's alfalfa yields per acre have become the highest in the world while water application rates have been reduced through an understanding of when irrigation is most beneficial. Plant breeding has been a key to increasing and sustaining high yields. Development of high-yielding varieties resistant to insects, diseases and nematodes has allowed the continued improvement of this crop in Arizona. Also of great importance has been the development of stand-establishment and management procedures that allow full stands to thrive for several years.

Research in 1979 and 1980 points to new ways of improving alfalfa yields either generally or in specific cases. New findings suggest that fertilization with potassium, and sometimes magnesium, may result in higher yields and more nutritious forage. Breeding results show that improved root systems and multi-leaflet leaves are hereditary traits and can be incorporated into new varieties. The same is true for tolerance to salt or heat.

Vegetables

The Arizona vegetable industry is characterized by production of fresh vegetables during the "off season" for distant markets. To market vegetables at specific times when production is down elsewhere, Arizona growers must manipulate growing schedules. This means that vegetables often must be grown under climatic conditions that are less than ideal. For example, lettuce must be planted in late summer when heat hinders the plants' early survival. The quality and quantity of irrigation for vegetables is also a critical concern. The perishability of vegetables that must be shipped long distances adds more complexity to this dynamic industry.

Research on bed shapes and water movement has revealed ways to reduce salt problems in lettuce and get uniform, early growth in lettuce and cantaloupes. Irrigation studies have led to improved efficiency and shown that overwatering reduces vegetable yield and quality. Recommendations for using essential inorganic fertilizers have been refined. A tissue-analysis technique now allows more precise fertilization during the growing season.

Work continues on breeding, evaluating and adapting new varieties and new hybrids of vegetables for Arizona. New lettuce varieties that extend harvest seasons allow production in new places, such as the Willcox area. Potato and carrot varieties adapted to Arizona conditions have been introduced. Cucumbers do not tolerate hot desert conditions as well as melons do, but considerable progress has been made in breeding a variety of melon that bears a fruit closely resembling a cucumber.

To keep Arizona vegetable growers competitive, new lettuce varieties are being developed that keep longer after harvest, especially when chopped for the wholesale trade. New packaging and shipping methods for lettuce and cantaloupes have reduced damage losses by millions of dollars. Use of plant growth regulators and new single-seedling planting techniques may improve early survival and growth for vegetables. Efforts to improve harvesting efficiency are also promising. Drip, sprinkler and dead-level irrigation systems are under study for various vegetables.

Seed Industry

Arizona's low humidity, control of water and other growing conditions favor the production of high-quality planting seed for many types of crops. Acreage for growing certified seed increased fourfold from 1969 to 1979, to more than 70,000 acres. Already the state produces a large portion of the cotton planting seed for the entire Cotton Belt. Information now available will allow expansion of this industry, and research should lay the basis for continued expansion. A shift to seed production will mean effective use of our unique production conditions. It will also provide growers with more profitable opportunities, since planting seed commands premium prices. Besides cotton, certified seed production in the state already includes small grains, alfalfa, sorghum, vegetables and other crops.

In spite of the great technological advances that have been made in Arizona crop production, continuing the success of growing traditional crops depends on development of even more advanced techniques, and on their rapid adoption by farmers. This is because technology is advancing in other agricultural regions and we must stay competitive. In Arizona, we must obtain the greatest possible efficiency in the use of our precious water.

Developing New Crops

The development of new crops offers a second way to use Arizona's productive soils and sunshine while reducing water use.

The opportunities to improve water efficiency for established Arizona crops are still substantial, as described in the two preceding articles. Development of new crops, however, will allow the fullest use of land where water is most limited. A listing of crop acreages in the state two or three decades from now may include substantial amounts for crops not showing up at all in Table 4, page 7. The key feature of such crops must be that they produce some useful product economically while using minimum amounts of water.

Rapid development of such crops challenges today's plant scientists. Virtually every one of our major crops has been developed over thousands of years. Only within the last century have scientists started to improve technically what had already been improved by informal selection since the dawn of history. Fortunately, plant scientists have a vast storehouse of knowledge about how plants can be improved through the domestication process. University of Arizona researchers have worked on developing new crops for arid lands for several decades, though efforts have intensified in the past five years. New crops developed in recent decades, through work here and elsewhere, include safflower, soy, guar and plantago.

The process is complex, expensive, highly technical and drawn-out. First, one must settle upon the species to be domesticated. This requires preliminary studies about the utility of products, the probability of success, technical barriers and other factors.

Once launched for a given species, the domestication effort demands a long-term commitment: Seed samples of the wild plant from throughout its natural range must be collected and stored to take advantage of its full genetic diversity. Basic studies about the biology of the plant, such as its patterns of reproduction and growth, lay the groundwork for improvements. Selective breeding focuses desirable traits into one or a few selected lines. A method for propagation, be it by seed or by vegetative means, is necessary for planting stands of the selected lines. Production practices, including pest-control procedures, must be worked out. So must processing and marketing techniques for the product. Development of ways to mechanize production and to use by-products improves the plant's chances for success. The economics and environmental implications of production require thorough analysis.

Proper Timing

The success of domestication depends not only on the fundamental suitability of the species selected, but also on good judgment in placing the right emphasis at the right time on these various steps in the domestication process. One pitfall is to attempt an economic analysis at an early stage without allowing for improvement in the target species through breeding and other research. Almost certainly, any wild plant would be declared economically unattractive if yields from the wild state were used in the economic feasibility study. But given adequate time and resources, selective breeding can dramatically change almost any plant species. Most plant species show wide variability in many characteristics when examined throughout their natural range. Where additional variability is needed, it can be generated through irradiation or chemical mutagens. Chromosome doubling and hybridization are powerful tools for genetic manipulation. Plant breeding, however, must also be part of a coordinated strategy for domestication. Preliminary studies of disease or insect susceptibility and climatic restrictions may dictate the direction for research.

The University of Arizona is a world-leading center for the domestication of new arid land plants. The UA College of Agriculture is making excellent progress on four potential new crops: buffalo gourd, jojoba, guayule and gopher plant. With just a foot or two of irrigation, each of these plants yields a product useful as either food or an industrial raw material.

Buffalo Gourd

This wild perennial gourd, native to the arid regions of western North America, may be the key to additional food and feed crops adapted to low-water-use agriculture. Buffalo gourd (pictured on page 22) probably grew in our western deserts long before the advent of man. It has been associated with American Indians for at least 9,000 years. They have used it for food, washing and medicine.

The buffalo gourd plant spreads efficiently even without seed. It sends out long vines along the ground. When the vines contact moist soil or sand, principally during summer rains, they sprout roots. This way, one plant may grow into a large, uniform colony.

Though rooting from runners is its primary method of spreading, buffalo gourd is also a great producer of fruit and seed. A single plant may have several hundred fruit, each about the size of a baseball and containing about 300 seeds with a total seed weight of two-fifths ounce. The dried seeds contain about 40 percent vegetable oil and about 35 percent protein. The oil is about 65 percent linoleic acid, a polyunsaturated fatty acid that is essential in the diets of humans and animals.

In addition to the oil and protein of the seed, the vine may be used as fodder for animals after frost kills it. The perennial root develops into a large, fleshy storage root containing about 18 percent starch, wet weight. A single root several seasons old may weigh 45 to 65 pounds.

The UA buffalo gourd domestication project began in 1976. The research group now includes a breeder-geneticist, a biochemist, a nutritionist, an agronomist, and their assistants and students. During the first three years, seeds were collected from 145 wild plants in an area from Nebraska to Mexico and California to Missouri. Plants from these seeds were evaluated in germplasm nurseries at the UA Agricultural Experiment Station in Tucson. Researchers made selections and crosses to quickly develop a relatively uniform seed source to use in test plots under various cropping conditions. Since buffalo gourd is a perennial, field plot research requires several growing seasons. This phase of research is not yet complete enough to permit a prediction of buffalo gourd's rate of success as a crop.

This plant grows in the wild with 10 to 12 inches of rain. Field plantings in Tucson have flourished with 10 to 16 inches of irrigation. It has the potential for economic yields of vegetable oil, protein and starch. Processing techniques for these products are simple, and virtually identical to those used for similar products from established crops. Buffalo gourd starch has been studied as an ingredient for puddings, and as an additive in plastics to make them biodegradable. Its small granular structure makes it a unique starch. The high-protein meal left after oil is extracted from the seeds can be used as animal feed or refined into high-protein flour for baked goods.

Whether this plant will achieve economic importance is still unknown. Research on it at the College of Agriculture has been supported by the Arizona Agricultural Experiment Station and the National Science Foundation.

Jojoba

Jojoba is an evergreen desert shrub native to Arizona, California, Sonora and Baja California. It produces large seeds that contain 40 to 60 percent liquid wax. Jojoba is the only plant known to produce this wax, which has a very different chemical structure than oils from convential oilseed crops. The wax has many potential uses, though its cost now limits its actual uses. Wax from wild plants is already being used in cosmetics, as a lubricant additive and for candle wax. If cultivation of jojoba can reduce the price of the wax, many additional uses may become practical.

Research on jojoba first concentrated on collection of plants from throughout its natural range. These collections are now under testing for yield and other features. Learning how to propagate the plant vegetatively (without seed) has required much work, but this process is now well developed. Now, superior shrubs can be multiplied quickly for uniform field plantings. Plantings have been established successfully using seedling transplants, rooted-cutting transplants and direct seeding. With each method, time of year and irrigation at planting are critical.

Attempts to cultivate jojoba during the past few years have yielded much new knowledge, but many questions remain. Planting trials throughout southern Arizona quickly demonstrated that jojoba is much more cold-sensitive than previously thought. Young plants and flower buds on older ones often die when temperatures reach the low 20s (F). Older plants can survive temperatures in the 12 to 15 degree range, but their flower buds and many of their branches are killed at such temperatures. Plants appear to differ considerably in their tolerance to low temperatures, so it is possible that cold-tolerant varieties can be developed. Using today's planting stocks, though, successful growing of jojoba is unlikely where winter temperatures fall below 25 degrees F.

Preliminary studies suggest that jojoba requires only one or two feet of irrigation annually, and much less fertilizer than conventional crops.

Weed control tops the list of remaining problems with jojoba as a crop. Jojoba grows very slowly its first two years, so it can be overgrown by weeds quickly. Hand weeding is too expensive. Better methods are needed.

Wild jojoba plants are now hand-harvested. For jojoba wax to drop in price enough to compete for larger markets, mechanical harvesting methods will be necessary. As yet, an acceptable mechanical harvester has not been developed.

Also needed is tested planting stock with known high-yielding ability and with a shape adaptable to mechanical harvesting. Currently, seed collected from the wild is being used for planting stock. Plants produced from such seed vary considerably in yield and other traits.

A large number of other questions also remain: What diseases and insects will be problems? What plant population is best? What is the best ratio of male to female plants (both are needed for seed formation)? When is the best time of year to plant? What do nutrient deficiency symptoms look like? How and when should plants be pruned? When should plants be irrigated?

By current estimates, 10,000 to 15,000 acres of jojoba have been planted in the United States, several thousand in Mexico and smaller amounts in several other countries. It is impossible to predict what the acreage will be a year from now. The prospects for jojoba becoming a major crop depend upon the resolution of the technical problems described above, upon the generation of a reliable supply of wax, and upon evidence of its utility in additional markets on an economic basis.

Research on jojoba in the College of Agriculture has been supported by the Arizona Agricultural Experiment Station, the National Science Foundation, the Four Corners Regional Commission and commercial firms.

Guayule

Guayule produces natural rubber. It is a perennial shrub of the Chihuahuan Desert of north-central Mexico and southwestern Texas. The plant is bushy with dense branches, a thick cluster of silvery leaves, and an extensive root system with a thick crown. At maturity the plants stand 25 to 40 inches tall.

Rubber for guayule is chemically identical to Hevea (rubber tree) rubber, which is in all our tires and many other rubber products.

Natural rubber makes up one-third of all the rubber used in the United States. It cannot be replaced by synthetic rubber because the elasticity, resilience, tackiness and low heat-buildup of natural rubber is essential in tires. The United States now imports nearly one billion dollars worth of Hevea rubber annually. Guayule grown on two million acres in the southwestern states could easily supply these needs.

Unlike jojoba, buffalo gourd and gopher plant, guayule has a history of cultivation. It was first grown under domestication in 1912 to 1916 in southern California. In the 1920s and '30s, a small but viable guayule industry existed, with about 12,000 acres in California and Arizona. During World War II, when Hevea rubber was unavailable from the Far East, the U.S. government created the Emergency Rubber Project, which absorbed the small guayule industry into a massive commercialization and research effort. The work in variety development and rubber processing continued until 1959. No further work was done until the University of Arizona began a guayule program in 1976. Fortunately, the best varieties developed in the 1950s were still available. Also, new varieties were collected in Texas and Mexico.

The UA guayule program now includes breeding and variety testing, agronomic research, and studies of rubber production in relation to water use.

Whether a guayule industry becomes commercially feasible depends on the development of production and extraction technologies, on rubber supplies and demands, and particularly on production economics. UA agricultural researchers are cooperating very closely with rubber-company researchers. This insures an orderly development that will give guayule its greatest chance for success.

The full development of the guayule industry will take about 10 to 15 years. The plants are harvested at about four to five years of age. To establish a minimum of 5,000 to 10,000 acres and build a pilot processing plant will take about five to seven years. If the whole industry appears feasible, another five to seven years will be needed to develop 50,000 to 100,000 acres and an economic-size processing plant.

The economics of guayule in Arizona will depend on water availability, value of land, and the economics of the individual farms. Based on preliminary data, guayule requires about 28 inches of water (including effective rainfall) the first year and about 18 to 20 inches annually in following years.

Guayule research at the College of Agriculture has been supported by the Arizona Agricultural Experiment Station, the National Science Foundation, the Four Corners Regional Commission and USDA competitive grants.

Gopher Plant

Euphorbia lathyris is an herb in the poinsettia family that usually grows to a height of 20 to 80 inches. Its common name, "gopher plant," comes from its alleged gopher-repellant quality. In fact, in northern California, gopher plant has been interplanted with various fruit and nut crops to protect them from gophers. Its future value, though, may be as a living oil well.

Gopher plant is primarily a weed of the temperate zones and is not native to the arid Southwest. UA researchers are trying to adapt it to Arizona as a petroleum fuel crop. As a producer of a crude, oil-like extract, gopher plant has tremendous potential for future use in the petroleum industry.

The search for superior plant types has identified lines that produce relatively high percentages of crude oil. In addition, gopher plant oil has been shown to be of greater economic value than conventional crude oil.

Agronomically, researchers began with little information about the cultivation of gopher plant, since its eradication from fields has been common practice for many years. Two years of study have indicated that a September or October planting can produce at least three tons of gopher plant per acre with a total of two acre feet of water. That makes four barrels of crude oil per acre using wild, unimproved seed and without optimizing water, fertilizer and pest control. Selection and genetic improvement of the wild seed, and improvements in field practices, should make it possible to significantly increase these yields to an economic level.

The major problem with gopher plant now is its susceptibility to fungal disease organisms. Various techniques are being tried to protect the plant from these diseases. The best method yet identified in Arizona is to avoid infection by winter cropping.

Given the infancy of gopher plant research, predicting the future of this crop in Arizona is difficult. However, with the increasing costs of producing fuel oil from reserve supplies, the need for a renewable fuel source may bolster the demand for production of gopher plant in the foreseeable future.

UA research on gopher plant has been supported by the Diamond Shamrock Corporation, the Arizona Agricultural Experiment Station and funds from the UA Vice President for Research.

Other Options

The progress made to date on these potential crops offers encouragement that one or more, or even all of them, may find a place in the future of Arizona agriculture. Also, these studies indicate that we are on the right track, and that a closer look should be taken at other low-water-use plants to find additional crop candidates worthy of attention. While the four species currently under investigation are meritorious in themselves, there is adequate reason to pursue the idea of new arid-lands crops more vigorously.

Possible benefits of the UA work extend beyond Arizona. Many areas of the world with climates like ours also need such new plants as crops. Arizona's worldwide leadership in this field includes graduate student training and interactive research to encourage such work in other countries. This, in turn, benefits Arizona since breakthroughs elsewhere could be applicable here. International attention to plant domestication projects will also increase the availability of useful candidate plants and seed collections.

Looking Ahead: Cooperation Needed

Arizona crop agriculture is highly productive and efficient, and contributes significantly to the economy of the state. Its cash receipts of $1.7 billion annually rank it as third or fourth among the state's industries that generate cash receipts.

Crop agriculture can continue to exist harmoniously in Arizona with an expanding urban population. However, the state cannot continue to overdraw its water supply by 2.2 million acre-feet annually. We must learn to live within the resources that are provided for us or that we can augment from other sources. The challenge is in recognizing the problems and solving them in logical ways that do not harm part or all of our society.

Changes should not be made precipitously, but only after careful analysis of the results of action. In a word, the essential element is research. Research can develop answers to minimize the undesirable results of drastic change, and help improve the quality of life for a growing population. Given sufficient time, it also decreases polarization by finding answers to problems that generate differences of opinion.

Crop agriculture must continue to adapt in the future to help the state reach a water balance. Inefficiencies in irrigation practices must be eliminated. However, urbanization will not decrease water use per unit of land. An acre of suburban housing uses about as much water as an acre of cotton. All water users must conserve.

The overdraft can be stopped without ruining agriculture. For example, an average reduction of one acre-foot of irrigation water for the 650,000 acres of Arizona cotton is reasonable to predict. On our remaining 550,000 acres of irrigated cropland, improved efficiency plus an increase in the proportion of land devoted to low-water-use crops might save 2.5 acre-feet per acre. This hypothetical scenario would cut the state's groundwater overdraft by more than 90 percent.

Procedures for growing traditional crops in Arizona will continue to change. Water savings will result from new short-season varieties, improvement in irrigation practices, and the optimizing of output in relation to all inputs rather than just maximizing yields per acre.

New, low-water-consuming crops also can help maintain crop agriculture in the face of a diminishing water supply. More research funding and less political tampering with research efforts are needed to speed development of these crops. This development must be coordinated with private industry. A crop of guayule is useless if industry is not ready to process it into rubber. Economists must be involved at every step to ensure that society benefits from projected developments.

The future of Arizona crop agriculture is bright. It can continue to contribute significantly to the state's economy even with a rapidly increasing urban population and constraints on the water supply. It can–if we all work together.

L. W. Dewhirst, Director
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