HP1263

Agriculture in Semi-Arid Environments

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1 Ancient Agricultural Systems in Dry Regions

H.W. LAWTON and P.J. WILKE

1.1 Introduction

More than 90% of the estimated 80 billion people that have ever lived out a lifespan on earth subsisted by scavenging, hunting, fishing, shellfishing, and gathering and collecting wild plants, insects, and other natural foods (Lee and DeVore, 1968a). Man did not practice agriculture for a hundred thousand generations. Hunting and gathering as a lifestyle may not have been as harsh as we usually imagine in terms of the human condition. In many respects, as plant geneticist Jack Harlan (1975) has observed, man's first three million years was truly his "Golden Age." Analogy with the few living hunting and gathering peoples that survive today in such remote regions as the Kalahari Desert of southwest Africa suggests that each adult seldom needed to spend more than two or three days a week on the food quest (Lee, 1968; Harlan, 1975). Insofar as we can infer, diets were well-balanced with adequate amounts of plant and animal protein, and starvation was probably rare. In all likelihood, it was a time of relative freedom from infectious diseases, which could not spread readily from one small, isolated, mobile group to another. It was not ignorance that kept prehistoric man from engaging in agriculture. There is increasing evidence that ancient hunters and gatherers had a sophisticated knowledge of the life cycle of plants and animals on which they relied for subsistence. Probably most hunting and gathering groups engaged in some forms of environmental manipulation (e.g., Downs, 1966; Bean and Lawton, 1973). Nevertheless, except for his possible role in the extinction of the Pleistocene megafauna of the New World, man's overall impact on the environment was not great. In essence, man was just another species in the landscape. Human population densities remained low, well below the carrying capacities of respective environments. Until 10,000 years ago, the total living human population probably never exceeded ten million (Lee and DeVore, 1968b).

Then, starting in the early Holocene, about 10,000 years ago, something happened in several regions of both the Old and New Worlds, something that was to change forever man's peaceful coexistence with nature. Man began to practice agriculture. Instead of being solely an acquirer of food resources, he became a producer of them. Although we no longer think of an agricultural revolution in the sense of a dramatic overnight appearance of a new lifeway (after all, it did take 3000–5000 years), the development of agriculture was indeed the most revolutionary event in the history of mankind when one considers its effects.

HP1264

Over substantial areas of the earth, the Golden Age of hunting and gathering was brought to a close. Natural and cultural checks on population were relaxed. Seasonally nomadic campsites were replaced by sedentary villages — then towns — and then cities as the capitals of warring states and empires. Diseases like malaria that highly mobile foragers simply outran and dietary deficiencies resulting from monotonous fares became a new dimension of reality (Stott, 1969). The natural environment in many areas was so drastically altered through overgrazing by domesticated animals, clearing of forests, introduction of alien weedy species, soil erosion, and the destruction of native fauna that any return to hunting and gathering would have been impossible. During periods of drought or social upheaval, mankind for the first time faced the threat of widespread famine. The beginnings of agriculture were revolutionary in the sense that the interval from 10,000 to 3000 years ago saw more dramatic changes in the behavior of the human species and in its role in modifying the landscape than had the entire Pleistocene. Small wonder it is that the origins of agriculture have received more study in recent years by archeologists, botanists, geographers, and other scholars of prehistory than probably any other subject.

Several recent works have synthesized this extensive literature, and some of these shed new light on the origins of agriculture. Significant works include *The Domestication and Exploitation of Plants and Animals* (Ucko and Dimbleby, 1969), *The First European Agriculture* (Murray, 1970), *Palaeoethnobotany: The Prehistoric Food Plants of the Near East and Europe* (Renfrew, 1973), *Farming in Prehistory* (Bender, 1975), *Crops and Man* (Harlan, 1975), *The Origins of African Plant Domestication* (Harlan et al., 1976a), *Origins of Agriculture* (Reed, 1977), and *The Food Crisis in Prehistory* (Cohen, 1977a). Some earlier, classic papers on agricultural origins were anthologized in *Prehistoric Agriculture* (Struever, 1971). In general, research on agricultural origins has focused on the problems of plant domestication. A literature survey reveals a surprising dearth of information on early agricultural systems. Three outstanding works that do examine agricultural systems of antiquity are *A History of Land Use in Arid Regions* (Stamp, 1961), *The Negev: The Challenge of a Desert* (Evenari et al., 1971), and *Early Hydraulic Civilization in Egypt* (Butzer, 1976).

Why man became agricultural largely remains a mystery despite three decades of intensive research and speculation. Once begun, food production offered a more efficient way of life (Leonard, 1973). Whereas before the advent of agriculture multiples of square kilometers of land had been required to support a single nuclear family, under intensive farming large numbers of people could be fed on a single square kilometer. Sedentary villages made possible increased food storage, raising larger families, development of specialized crafts, and offered other amenities. Yet these benefits — as opposed to such drawbacks as less leisure time and harder labor — were not immediately foreseeable to nomadic groups embarking on agriculture in the early Holocene. Nor do any of these benefits necessarily constitute the impetus for the agricultural revolution.

Cohen (1977a) reviewed the many hypotheses that have been put forth since the time of the nineteenth-century economist Thomas Malthus to account for the shift from hunting and gathering economies to agricultural technology. Several recent hypotheses focus on the concept of stress or population/resource disequilibrium as the causal factor in the origins of agriculture. Childe (1951) argued that climatic change at the end of the Pleistocene pushed man into agriculture, but more recent research has discredited his postulated drought. Braidwood (1960) viewed agriculture as resulting from increasingly intensive use and manipulation of local flora and fauna. Both Flannery (1968) and Binford (1968) have suggested that population/resource disequilibrium occurred at about the end of the Pleistocene and that food production arose out of necessity. In contrast to the stress hypotheses, Isaac (1970) related agriculture to the emergence of a new "world view" and ceremonial practices appearing at the end of the Upper Paleolithic. These are only a few of many theories advanced over the past three decades to explain the origins of agriculture. In exploring these hypotheses, Cohen (1977a) concluded that the nearly simultaneous adoption of agriculture in several areas of the world about 10,000–8000 years ago could only be accounted for by assuming that hunting and gathering populations had saturated the world and exhausted all strategies for increasing their food supply within the constraints of their lifestyle. While Cohen's explanation for the origins of agriculture is unlikely to prove to be the final word on the subject, his ideas are stimulating and his synthesis was long needed. What seems clear is that the causes for the development of agriculture are probably complex, vary from region to region, and are likely to remain elusive for a long time to come.

One observation that emerges from a review of the works cited above is that a surprising number of early agricultural economies, both those of independent origin (such as in Peru, the Southern Mexican Highlands, and the Near East), and those that were recipients of farming technology diffusing from such centers of origin (including the American Southwest and the Nile Valley), developed in drier regions of the world. Furthermore, although much of the recent literature provides a good treatment of the chronology of events in the so-called agricultural revolution and of the origin and development of particular species of cultigens, it generally tells us less than we would like to know of the methods and techniques employed by early farmers. This is a definite shortcoming, inasmuch as the methods employed by prehistoric farmers are in many cases the same ones that form the basis of agricultural technology in underdeveloped countries today. The problems faced by farmers of antiquity are the same problems confronting subsistence farmers in the twentieth century. If we are to understand contemporary subsistence farming it would be well to digress at the beginning of this volume and examine briefly the available information on the technology of early agricultural systems in dry regions.

The history of ancient agricultural systems in dry regions is the story of man's efforts to solve problems with water and the lack of it. Such efforts include attempts to farm given the vagaries of chronically deficient rainfall, the utilization of surface runoff and the collection and channeling of runoff for watering crops, the use of floodwaters from ephemeral and perennial streams, and the development of various forms of irrigation. The following are some of the kinds of agricultural systems employed in antiquity, all of which may be found in various parts of the world today.

Dry farming is cropping without any attempts to use runoff water or provide additional water through irrigation for plants during critical growth periods. Dry

HP1265

farming is dependent solely on the water available from rainfall and snow. Sowing is often done in advance of expected rains that may or may not be adequate to ensure proper growth and maturity of crops. Thus, dry farming often results in years of adequate to good yield interspersed with years of low yield or no yield at all. Fields are more often planted than harvested. While dry farming was undoubtedly the standard method of cropping for many semi-arid regions in prehistoric time, it is not likely to have left substantial evidence in the archeological record. Usually, we must infer dry farming when no physical evidence is found of attempts to provide crops with additional water.

Runoff farming is farming in places where crops receive water as runoff from adjacent unprepared slopes. Individual fields or gardens are usually small and situated where they will receive maximum available runoff. The fields may be located in natural catchment basins and may be enclosed by low stone or earthen borders to contain and conserve moisture. Fields may consist of narrow strips of crops along contour-terraced hillsides or they may be small garden plots behind check-dams made of stones in the beds of intermittent streams. These are water-conservation as opposed to water-harvesting systems (cf. Vivian, 1974). We draw a distinction between runoff farming, water harvesting, and floodwater farming systems.

Water harvesting is the collection of runoff water from prepared watersheds. The slopes are cleared of vegetation and loose rocks and may be compacted or graded further to induce runoff, which is then channeled to fields. Recent experiments with water harvesting have shown that surprisingly high "yields" of water can be achieved from even very minor rain showers. Much recent effort has been devoted to experiments with various soil covers and treatments to enhance runoff (Frasier, 1975). Water harvesting was one of the important agricultural systems in antiquity. Evenari and his colleagues have discussed at length the ancient and highly successful farming systems that employed water harvesting in the Negev Desert of Israel (Evenari et al., 1961, 1968, 1971). Their experiments on the reconstruction of these agricultural systems are discussed below. Both runoff farming and water harvesting are characteristically agricultural systems in semi-arid and arid regions.

Floodwater farming is a confusing term in the literature. Some early investigators, notably Bryan (1929), failed to draw a distinction between runoff farming and floodwater farming. We refer to floodwater farming as farming in places where fields are watered either by small flash floods in or at the mouths of ephemeral stream channels or on the flood plains of larger streams and rivers where fields are overflowed by floodwaters. In each instance, it is floodwaters concentrated by natural watersheds rather than direct run off from adjacent slopes that waters the crops. Examples of the former are the *Ak-Chin* (arroyo mouth) fields of the Hopi Indians of Arizona in the southwestern United States, which are still used today (Hack, 1942). Examples of the latter are the early agricultural systems on the floodplain of the Nile before the advent of true irrigation (Butzer, 1976) and those of the Yuman-speaking Indian tribes of the Lower Colorado River (Castetter and Bell, 1951).

Irrigation farming is farming with the aid of a regulated supply of water introduced when needed to aid the growth of crops. It differs from water harvesting

HP1266

in that it does not specifically capitalize on ephemeral rain waters. The sources of water are generally thought of as something more permanent: streams or rivers, reservoirs, wells, *qanats*, etc. Irrigation systems may employ such features as dams to impound the flow of ephemeral or perennial streams and headgates or other control devices to release the water at will. Other important features of certain irrigation systems are canals or ditches to transport water to the fields, which are flooded with the aid of retaining dikes, or otherwise to distribute it to the plants. Some irrigation systems employ lift wheels to raise water from one level to another. Of lesser importance is pot irrigation: the watering of plants by hand from jars or other vessels. Irrigation systems employing large canals were operated for 1500 years by the Hohokam culture of the Gila and Salt River valleys of Arizona, in the southwestern United States (Haury, 1976). Dynastic Egypt saw the development of enormous irrigation systems (Butzer, 1976). The importance of irrigation in the ancient world is apparent in the term "hydraulic civilizations".

In actuality, many early farmers employed combinations of these agricultural systems, and in many regions the functioning systems changed over time. Sometimes a shift in a system was made out of temporary expediency. Various Indian groups of the southwestern United States resorted to pot irrigation when their crops failed to receive sufficient moisture through other means. An example of a system changing over time is that of the Nile Valley, where floodwater farming gradually gave way to actual irrigation.

In the next section, we present only a brief outline of the beginnings of agriculture, since the focus of this chapter is on agricultural systems in dry regions. The discussion of agricultural systems in the Old and New Worlds makes no attempt to present a definitive summary. Instead, we describe some of the better-known agricultural systems of antiquity and how they functioned. Some of these agricultural systems are more ancient than others; some of them continue in use today unchanged by modern technology. Present dryland farming systems are discussed by Bowden, this volume, Chapter 2.

1.2 The Beginnings of Agriculture

Until thirty years ago, the earliest known agricultural settlements were those of the Nile Valley, dating back to about 4500 B.C. In 1948, Robert J. Braidwood of the University of Chicago set out for the Near East to prove that agriculture stretched farther back in time than anyone had imagined. In choosing a site, he selected the foothills of the Zagros Mountains in northeastern Iraq, where a constellation of wild cereal grasses, other plants, and animals occurred in nature that later became the basis for agriculture. Three seasons of excavations at Jarmo, a site dated about 6500 B.C., led to the discovery of cultivated two-rowed barley and emmer and einkorn wheat (Braidwood and Howe, 1960). Additional evidence was found of domesticated sheep, pig, goat, and probably dog. This pioneer research set the stage for an explosion of knowledge so great that new discoveries have forced a revision of current views on agricultural origins almost every five years.

The most recent radiocarbon evidence indicates that the first cultivated plants, squash (*Cucurbita* sp.) and bottle gourd (*Lagenaria siceraria*), appeared in the New

display the same deposition of travertine as noted at Hierve el Agua in the Valley of Oaxaca. Old canal systems are conspicuous by their "fossilized" channels. Some of these have a meter or more of travertine deposits and in places lie well above the eroded land surface; both factors suggest considerable antiquity. A few ceramic sherds found imbedded in the travertine also help to date these old canals. In many places deposition of travertine ultimately forced the abandonment of canals and the excavation of new ones alongside the older *tecoatle* "stone snakes" that wind across the landscape. The fossil channels document use of water from the mineral springs for irrigation purposes for the last 1500 years.

An elaborate system of chain-wells is presently in use in the Tehuacán Valley. These are in every sense analogous to the *qanats* of the Near East. Inasmuch as this type of hydraulic system was in use in Iberia at the time of the Spanish Conquest, it seems most reasonable to conclude that it was introduced to the New World in the sixteenth century.

Woodbury and Neely (1972) also described extensive terrace systems in the Tehuacán Valley that functioned, according to present interpretations, to retard the downslope movement of water and soil and provide arable soil for farming. These include both "hillside" and "valley" systems. By association with ceramic sherds, the hillside systems are dated as early as the Palo Blanco phase (ca. 200 B.C.), and their construction and use continues to the present. In area, these farming systems range from less than one to more than 35 ha. Introduction of the plow (by the Spanish in the sixteenth century) was no doubt instrumental in the abandonment of many of the known terrace systems, since the plow is not suited for use on rougher terrain that formerly could be tilled by hoe. Thus, many of the older systems are badly eroded and washed out. The fact that similar terraced farming is carried out today in the Tehuacán Valley on a large scale (Smith, 1965) strongly argues that the ancient terraces functioned in the same way.

Sometimes in association with the hillside terraces are the so-called valley terrace systems. These are a series of stone check-dams built across minor intermittent stream channels. Their function is basically the same as that of the hillside terrace systems, and the cultivable area of 42 examples studied ranges up to 14 ha. Indications are that few, if any, of the known examples of valley terrace systems are as old as the contour terrace systems on hillsides.

Analogy with contemporary farming practices is important to the interpretation of archeological terraces in Tehuacán Valley. In a following section on the North American Southwest it will be noted that hillside contour terraces and check-dams in Arizona, Colorado, and New Mexico are considered to have functioned in the same manner as the Tehuacán examples, but those of Sonora and Chihuahua are thought to have been built solely to inhibit runoff. It is apparent that the function of these ancient terrace systems will be revealed with certainty only after exhaustive study that would include pollen analysis of sediments of a large number of such structures in various regions and settings.

1.4.1.3 The Basin of Mexico

We may also draw attention to the Basin of Mexico (elevation 2250 m), since it is in that region that some of the most spectacular urban centers in all of

Mesoamerica rose and fell, and these urban centers could not have existed without a firm agricultural base. Because the present climate is semi-arid and a strong reliance is placed on irrigation today in the Basin of Mexico, we can probably assume that it played an important role in the past.

One of the largest urban centers to ever exist in pre-Columbian Mesoamerica was Teotihuacán. This city rose to prominence shortly before the time of Christ and by A.D. 500 had an estimated population of 50,000 to 100,000 (Millon, 1967). The city has been mapped in detail by Millon (1973) and covers about 19 km^2. Surprisingly, despite the detailed mapping and considerable archeological excavation, no evidence of canal irrigation dating to Teotihuacán times has been found. Today irrigation agriculture in the Teotihuacán Valley draws in large part on water provided by some 80 springs near the town of San Juan, adjacent to the ruins of Teotihuacán. It is entirely possible that irrigation was carried on in the lower part of the valley at the time Teotihuacán flourished, and that all evidences of it have been either obliterated or obscured by later activity. This is suggested indirectly by examination of the Teotihuacán map, which shows that ancient watercourses were canalized through the city in accord with the compass orientation of the metropolis (Millon, 1973). Thus, hydraulic technology is not a question. There are also *chinampas* in the region about San Juan where the springs come together, and these may date to the time of the great city. *Chinampas* are artificial linear-shaped islands created by mounding up aquatic vegetation and soil in marshy places or in shallow water and excavating channels between the islands. They are watered by hand from the adjacent channels, and are also sub-irrigated. They are extremely productive farming plots.

At the time of the Spanish Conquest in 1519 substantial areas of the large shallow lakes of the Basin of Mexico were converted into a network of canals and artificial islands farmed with *chinampa* agriculture. Dikes and causeways extending across the lakes helped to maintain constant water levels and thereby prevent drying or flooding of the *chinampas*, to separate the freshwater bodies from saline ones, and even to convert portions of saline bodies into fresh ones for expanding *chinampas* (West and Armillas, 1950; Palerm, 1961). The *chinampas* formed the agricultural basis of the Aztec state and civilization, and their use may in fact date to Teotihuacán times. Also of importance at the time of the Conquest were farming on the slopes of the adjoining uplands using existing rainfall and runoff from above (with or without terracing) and canal irrigation of the floor of the basin.

1.4.2 The North American Southwest

Several regions of the North American Southwest saw the development of agricultural economies in prehistoric time. The earliest known evidence of agriculture in the Southwest comes from Bat Cave, western New Mexico, where small maize (*Zea mays*) cobs were found in deposits dating to about 2000–2300 B.C. (Dick, 1965; Manglesdorf et al., 1967). The elevation of this site is over 2000 m above sea level, and it is believed by many that agriculture spread into the American Southwest from the Mexican cordillera, the cultigens only later becoming adapted to lower elevations.

HP1267

Nothing is known of the agricultural system represented by the maize from Bat Cave. The adjacent environment is today without running streams for irrigation and crops may have been grown by dry farming or runoff farming, capitalizing on a summer-dominant rainfall pattern. About 300 B.C. extensive irrigation systems were begun by the bearers of the Hohokam culture of the Sonoran Desert of Arizona. Later archeological evidence from the Colorado Plateau, assigned to the Anasazi culture, provides details of the runoff farming and irrigation systems that formed the basis of the agricultural economies. A very extensive terracing system has also been studied in northwestern Chihuahua and northeastern Sonora. In early historic time (post-A.D. 1540), we have detailed observations of floodwater farming among the Yuman tribes of the Lower Colorado River, and irrigation agriculture among the Paiute of Owens Valley, eastern California. The Hohokam and Anasazi cultural traditions also continue to the historic present with little change in basic agricultural technology, as shown by the Pima and the various Pueblo tribes, respectively.

1.4.2.1 The Hohokam

The agricultural system of the Hohokam has been studied in perhaps the greatest detail. The Hohokam were the master irrigators of the Gila and Salt river valleys of Arizona. Recent work at Snaketown, one of the largest Hohokam villages (Haury, 1976), reveals that the roots of the culture probably lie in a direct migration from Mexico. Settlement of Snaketown and construction of the earliest irrigation canals, which took water from the Gila River, occurred by 300 B.C. Throughout the more than 1500 years of occupation, the major crop was maize, and the common bean (*Phaseolus vulgaris*) was grown from about the time of Christ. Cotton (*Gossypium* sp.) was grown after about A.D. 100. The tepary bean (*P. acutifolius*), squash (*Cucurbita* sp.), and probably the bottle gourd (*Lagenaria siceraria*) were also grown, but their dating is less certain.

Some of the irrigation canals of the Hohokam were of large proportions. Woodbury (1960) reported that the main canals at Pueblo Grande were traceable for up to 15 km and were as much as 3 m deep and 11 m wide. They were lined with clay to retard seepage and are thought to have been constructed in the twelfth and thirteenth centuries A.D. At Snaketown none of the canals was this large. The earliest main canal was broad and shallow, but they took on a narrower and deeper profile over time. Work at Snaketown has revealed the details of how smaller canals or ditches branched off from the main canals. At such places dams, apparently built of stakes and mats of some kind, were used to divert the water into lateral ditches. Stratigraphic excavations revealed a long series of superimposed canals, with an overall reduction in canal size over time. This is thought to be related to more efficient water management during the later periods of occupation. The main canals show an average grade of a little over a meter per kilometer, very close to the figure advocated for earth ditches today (Haury, 1976). That silting was a constant problem is evident, however, from the mounds of silts that were removed from the canals in antiquity.

In all probability, the Hohokam of Snaketown found it necessary to leach the salts from their fields as arid land irrigators do today. Had they not mastered this problem, it is doubtful that the village could have survived for a millennium and a half. There is no reason to believe that any central hydraulic authority was needed to construct and maintain the canals at Snaketown. Where several villages cooperated and depended on the same canal, however, some form of intervillage management authority must have existed (Haury, 1976).

Bohrer's (1970) study of the plant remains from Snaketown reveals that a number of noncultivated species were important food items throughout the period of occupation. These included saguaro (*Carnegiea gigantea*), mesquite (*Prosopis juliflora*), and screwbean (*P. pubescens*), as well as other species. The Pima are considered to be the descendants of the Hohokam and farm the immediate area today. By analogy with their subsistence practices, and in consideration of the plant remains found, Bohrer believes both irrigation agriculture and gathering of wild plants were important to the Hohokam. The Pima generally raise two crops a year. The first planting occurs in March after the killing frosts, and winter rains and snow melt furnish water for irrigation. Wild plants and stored foods carry the Pima through until harvest in July, when they also gather saguaro seeds. The second planting occurs in July or August and is nourished by irrigation water provided by summer thunderstorms (see also Castetter and Bell, 1942). While this crop is maturing, mesquite is harvested as an additional resource. Haury (1976) notes that faunal remains were not abundant, and hunting and fishing, although practiced at Snaketown, do not appear to have contributed greatly to the subsistence economy.

Snaketown was abandoned about A.D. 1200, but other Hohokam sites continued to be occupied for perhaps 200 years longer. The decline of the Hohokam is believed not to have resulted from any failures in the agricultural system. It is probably rooted in a complex series of causes that brought about an overall collapse of southwestern cultures in the thirteenth and fourteenth centuries. Although Snaketown was abandoned, the Pima still occupy the Hohokam territory and continue with little change the ancient tradition as subsistence farmers of the Sonoran Desert lowlands.

1.4.2.2 Lower Colorado River Tribes

The classic example of floodwater farming in the American Southwest is that of the Yuman-speaking tribes of the Lower Colorado River, and to a lesser extent the Lower Gila River (Castetter and Bell, 1951). The antiquity of the farming system is unknown, but it is thought to date to prior to A.D. 1000. The snowpack in the Rocky Mountains, where the Colorado River rises, was usually adequate to insure substantial flooding on the lower river prior to damming and diversion in the twentieth century. There the Mohave, Yuma, Cocopah, and other tribes cleared garden plots in former sloughs, lagoons, and river channels on the floodplain and in the delta in advance of the expected early summer floods. The floodwaters overflowed the cleared garden plots, saturated the soil, and deposited a layer of silt. The Indians then planted their crops on the retreat of the floodwaters and the plants matured without additional watering. Sometimes weirs were built of stakes, brush, and logs extending out into the channel of the river to divert water into swales (probably old river channels) extending away from the main channel. The swales were dammed at intervals to impound floodwaters in a form of flood irrigation.

HP1268

When the first impoundment was filled and the soil thoroughly saturated, the dam was broken and the second allowed to fill, and so on. True ditch irrigation apparently was unknown prior to contact with the Spanish.

The floodwater farming system of the River Yumans was dependent solely on the annual floods. Sometimes there was no substantial runoff and among the Mohave, pot irrigation nourished some small gardens; at other times there were two or three peaks in the flood resulting in destruction of the newly planted crops.

Chief among the crops were maize, tepary beans, and squash (*Cucurbita moschata*), and a little cotton was grown. After the arrival of the Spanish in A. D. 1540, wheat, barley, watermelons (*Citrullus lanatus*), muskmelons (*Cucumis melo*), and cowpeas (*Vigna unguiculata*) were added to the list of cultivated plants. Maize was clearly the most important cultivated crop, and much of it was eaten before maturity, in the roasting ear stage. Squashes were cut into strips and dried, and watermelons were buried in sandy places for winter use.

Villages located on the floodplain were abandoned during the annual floods, and temporary residences were set up nearby on the higher river terraces. Ordinarily wild plant foods [especially mesquite (*Prosopis juliflora*)], fish, and game animals constituted 50% to 70% of the diet. In years of crop failure, the Indians relied solely on hunting and gathering.

On the Lower Gila agriculture was of less importance than on the Lower Colorado. The major floods on the Gila occurred in January and February, and planting was done immediately after the floodwaters subsided (Spier, 1933). A second crop was also sown in mid-summer. Although the data are not complete, it would appear that summer thunderstorms were important in providing water for this crop.

1.4.2.3 Owens Valley Paiute

A hitherto little-known agricultural system of apparent indigenous origin and perhaps considerable antiquity existed in early historic time among the Paiute of Owens Valley, eastern California. This system was based on the irrigation of a number of wild plant species, there being no traditional American domesticates under cultivation. Lawton et al. (1976) reported that streams descending the eastern slope of the Sierra Nevada Mountains were diverted with dams and ditches in the spring to water crops of yellow nut-grass (*Cyperus esculentus*) and wild hyacinth (*Dichelostemma pulchella*). The tubers and corms of these species were important food items and formed the basis of a vegeculture system that was unique in North America. Other wild plants also benefited from the irrigation and grew on the areas overflowed by irrigation wastewater, but these were not of as great importance as those listed above. Many details of the system are still lacking since it is known only from early surveyors' accounts and brief ethnographic notes (Steward, 1930). However, one of the ditches was about 8 km long, and the irrigated areas were very large, being multiples of square kilometers in area. This agricultural system warrants detailed archeological investigation.

1.4.2.4 Anasazi

Vivian (1974) described in detail the water control systems of the ancient farmers of the Colorado Plateau, essentially the Four Corners region of the

Southwest where the states of Arizona, New Mexico, Utah, and Colorado converge. This region is that of the Anasazi or Pueblo culture, but many of the observations made there describe as well the agricultural system of the Mogollon, their neighbors to the south. The known agricultural systems date to approximately A.D. 1000 to 1300. Vivian notes that while irrigation from permanent water sources did play a role in this region, the overall pattern was one of collecting runoff for watering small garden plots.

Essential features of the system included *bordered gardens*, small garden plots bordered with stone (and formerly earth?) retaining walls to conserve moisture; *gravel-mulched gardens*, garden plots with a mulch of fine gravel to retain moisture; *check-dams*, small stone dams in intermittent stream channels to trap soil for gardens and to intercept and retain moisture; and *contour terraces*, low stone and earth terraces on the contour of slopes to retain soil and inhibit runoff. Most of the prehistoric systems of the Anasazi subarea employed combinations of these features.

Palynological studies in the Southwest suggest that the period from the eighth to the twelfth centuries A.D. was one in which there occurred a shift from a winter-dominant to a summer-dominant precipitation regime (Schoenwetter, 1970; Schoenwetter and Dittert, 1968). Winters were somewhat milder, the spring drought period was lengthened, and a larger proportion of the annual precipitation came in the form of intense summer thunderstorms. The above-mentioned water conservation devices are seen as an adaptation to these conditions, and their construction coincides with the shift to increased summer rainfall.

Chapin Mesa is the largest of the several finger-like mesas that together comprise the Mesa Verde of southwestern Colorado. In an excellent summary, Rohn (1963) described the agricultural and hydraulic features in evidence on Chapin Mesa. Although the mesa was occupied for perhaps 500 or more years previously, the major evidences of farming systems date to the late Pueblo II and Pueblo III periods of the Anasazi sequence (ca. A.D. 1000–1300) and provide a good example of Anasazi agricultural and hydraulic technology.

Rohn (1963) believes that prior to late Pueblo II times, farming was carried out on the mesa top and that gradually much of the soil on these cleared lands became depleted in fertility and lost to erosion. Although use of the mesa top for farming purposes continued, the major fields or gardens in evidence today are concentrated in shallow washes leading down from the mesa top to the canyon floors 100–200 m below. In these intermittent stream channels the Anasazi constructed low stone check-dams. The check-dams number from 3 to more than 60 in a single channel, providing small stair-step garden plots in series. Of simple coursed dry-laid masonry, the dams average about 5 m long and one-half meter in height. More than 900 such structures have been found on Chapin Mesa alone. The soil captured behind the dams is of fine texture and fertile, and the gardens were watered by simple runoff of summer rain waters from the mesa top. In some cases there is evidence that diversion channels were employed to augment the natural runoff to the check-dam garden plots. The total area of agricultural land provided by the approximately 900 known check-dams on the mesa is only some 8–12 ha. Contour rock terraces are common on nearby Wetherill Mesa (Hayes, 1964), and occur also on Chapin Mesa. These would have substantially increased the amount of available agricultural land, but it should be remembered that the Anasazi, although

HP1269

sedentary pueblo dwellers, were not fully agricultural but probably placed a greater emphasis on hunting and gathering for subsistence than they did on farming.

Since the Mesa Verde averages more than 2000 m above sea level, the growing season is short and only one crop of maize, beans, and squash could be grown annually.

Some of the larger check-dam systems on Chapin Mesa have, additionally, small masonry structures of one to several rooms, called field houses. These are thought to have served as temporary quarters for persons tending the fields and as storage facilities for the crops harvested.

On the top of Chapin Mesa are found impressive ruins of a substantial water system. The system includes a series of collection ditches in a natural catchment of about 10 ha and a feeder ditch that transported water to Mummy Lake, a reservoir about 1 km away. Mummy Lake is a circular masonry and earth-walled reservoir some 27 m in diameter. This ditch and reservoir system functioned primarily to provide domestic water for the Far View ruin group located just below Mummy Lake. There is, however, at least one distributary leading from the feeder ditch to a series of check-dams, and it thus appears that the system had a secondary function of irrigating a group of garden plots. A substantial ditch (called the Far View ditch) extends from the general vicinity of Mummy Lake southward for some 5 km. No connection with Mummy Lake has been found, however, and this ditch takes a definite swing around the Far View ruin group. It must therefore have been dug while these ruins were occupied and the inhabitants were receiving their domestic water from Mummy Lake. It seems probable that Mummy Lake had priority on waters collected in the basin above, and that surplus waters were diverted down the mesa top by the Far View ditch to a series of pueblos having only very limited local water supplies. The Far View ditch was up to 9 m wide and 1 m deep and its course is marked by a number of intakes for the collection of additional water along the way and outlets for irrigating mesa-top fields. It thus served both to provide for irrigation and to supply reservoirs for domestic use. The entire Mummy Lake–Far View water system was dependent solely on runoff, there being no springs to supply it.

Another setting which exemplifies agricultural technology of the Anasazi is the lower Chaco Canyon in northwestern New Mexico (Vivian and Matthews, 1965; Vivian, 1970). The lower 14.5 km of the canyon was probably the most densely settled area of its size in Anasazi territory. Vivian (1970) notes that by A.D. 1050 this confined area averaging only 1 km in width supported no less than nine large villages of several hundred rooms each (including Pueblo Bonito with over 800 rooms), four small pueblos of 30–100 rooms, and at least 50 smaller settlements of 10–20 rooms, for a total of nearly 10,000 people. Total available farmland in the canyon did not exceed 810 ha, but this land was intensively cultivated utilizing the runoff from intense summer thundershowers.

The Rincon-4 North farming system near the ruin of Peñasco Blanco is perhaps typical of the lower Chaco. Runoff water from one of the branch drainages of the canyon was collected by means of a diversion dam and channeled into a canal 4.5 m wide and 1.4 m deep that was in some places masonry-lined. The canal extended for 230 m to a multiple headgate which also received runoff by means of a ditch from a nearby slope. The water was then channeled to a grid of bordered gardens totaling

9.7 ha. The entire field complex was divided into quarters, each with 84 earth-bordered gardens. Individual gardens were watered by means of perimeter and bisecting ditches simply by creating openings in the earthen borders.

Farther to the south in Mogollon territory Woodbury's (1961) study of the agricultural systems at Point of Pines, eastern Arizona, is also of interest. This region is characterized by numerous check-dams and contour terraces ("linear borders"). The primary crops grown here were maize, kidney beans, tepary beans, and squash, and the dating is roughly equivalent to that noted for the Anasazi to the north.

Hack (1942), in an impressive study, described the present agricultural practices of the Hopi of northeastern Arizona. These probably date with little change to the late thirteenth century. The emphasis among the Hopi is on floodwater farming with the ratio of drainage basin to cultivated land on the order of 30:1. These *Ak-Chin* fields are planted at the mouths of arroyos or other drainages and are watered by the concentrated runoff from summer thundershowers. Other fields are situated where they receive the natural seepage of springs or are irrigated from reservoirs. All of these settings, the Mesa Verde, Chaco Canyon, Point of Pines, and the Hopi territory are of high elevation, being from 2000 to 2500 m above sea level.

1.4.2.5 Casas Grandes

To the southeast, in the northwestern part of the Mexican state of Chihuahua and adjacent parts of Sonora, there is evidence of a water control system of astounding proportions. This system was built about the middle of the eleventh century and functioned primarily to manage the flow of the Casas Grandes River (and other rivers across the continental divide) to prevent flooding and provide for irrigation and domestic water supplies (DiPeso, 1971, 1974; DiPeso et al., 1974; Herold, 1965).

More than 12,000 km² of uplands drained by the Casas Grandes River were subjected to conservation efforts through what has been called a surface water-soil retention system (DiPeso et al., 1974). Check-dams were built in every arroyo to slow runoff, contour stone terraces ("linear borders") of low profile and others of more substantial size slowed runoff from hillsides, and thus the furor of thunderstorms was brought under control. The combined effect of these *trincheras*, which involved enormous human effort in their initial construction and in their maintenance, stabilized the flow of the river and permitted the cultivation of some 80,000 ha of fertile bottomland. It was on these bottomlands that crops were irrigated with an intricate system of canals.

Many details of the functioning of the agricultural system are lacking, but it is thought that the upslope treatments, which in the Anasazi-Mogollon area functioned to retain both soil and moisture for agriculture, served only to slow runoff. This interpretation arises from the fact that many of them are located far above the elevation at which agricultural crops can presently grow, and the fact that pollen of cultivated plants has not been found in the sediments they contain. An adjacent region along the Rio Gavilan, across the continental divide, has been studied by Herold (1965). His findings essentially parallel those from the Casas

HP1270

Grandes drainage. Palynological studies of *trinchera* sediments failed to disclose any pollen of cultivated plants. This lends credence to the notion that the structures were distant parts of a lowland agricultural system and did not function as garden plots themselves.

1.4.3 South America

Our focus for a very brief look at ancient agricultural systems in dry regions of South America is on the Central Andes and the adjoining narrow desert strip along the Pacific coast from the equator to about 20°S latitude. Basically, the region is that of Peru, the Bolivian Highlands, and northern Chile. This area saw not only the indigenous development of agriculture, but also a succession of high cultures and civilizations with notable achievements in art, ceramics, textiles, metallurgy, domestication of animals, and large-scale irrigation and land reclamation projects.

The area is one of great environmental diversity, but is overall characterized by the extreme elevation of the Cordillera Occidental, the steep Pacific slopes of the mountains, and a narrow coastal plain. Offshore is the cold Humboldt current, and onshore winds are chilled and lose their moisture long before reaching land. Thus, although the sea coast is one of the most productive marine environments to be found anywhere, the coastal plain is extremely dry, being watered only by the many small rivers that rise in the Andes.

Although the small coastal valleys and adjoining desert areas were the locations of the great agricultural developments of antiquity, farming did not begin there. Crops were first brought under domestication in the higher Andean valleys at times that are probably comparable with the origins of farming in Mesoamerica, and later spread to the Peruvian coast (Pickersgill and Heiser, 1977; Kabaker, 1977; MacNeish et al., 1975; MacNeish, 1977). In addition, some of the important crops of Mesoamerica diffused into South America. Others originated in the Amazon basin. Since the nature of early farming systems in the higher Andean valleys remains obscure, we shall focus on agricultural developments along the coast.

The details of agricultural history on the coast of Peru differ from one region to another, and the details of early agricultural methods are obscure and largely inferred, but the general picture can be deduced from literature (Cohen, 1977b; Moseley, 1974; Farrington, 1974; Lanning, 1967). Agriculture appeared on the central coast before 2500 B.C. In a sedentary, coastal, maritime-oriented setting with a strong emphasis on the exploitation of fish, shellfish, and sea mammals, there was also the bottle gourd and squash. At about this time, and still in the maritime setting, a substantial list of crops began to appear, including cotton (*Gossypium barbadense*), new varieties of squash, jack beans (*Canavalia* sp.), peppers (*Capsicum baccatum*), lima beans (*Phaseolus lunatus*), *jicama* (*Pachyrrhyzus tuberosus*), peanuts (*Arachis hypogaea*), and possibly sweet potatoes (*Ipomea batatas*). There is no agreement whether irrigation was practiced at this time. Some scholars believe that it was, but most are of the opinion that crops were grown on the floodplains of the rivers taking advantage of the moist soil and perhaps also utilizing floodwater farming. Land suitable for such purposes is extremely limited in nearly all river valleys and many of the coastal villages with

agricultural remains are located at a considerable distance from river floodplains. It is possible that primary producers of agricultural products resided in inland sites along the rivers and exchanged them for marine products from the coast.

There is a growing impression on the part of some scholars (e.g., Moseley, 1974) that the increasing coastal populations engaged in some floodwater farming ultimately reached the practical limit for further expansion about 1800 B.C. Shortly thereafter, many of the coastal sites were abandoned, and instead there appeared inland, along the river valleys, settlements that are classified as towns displaying monumental architecture. Their setting was still suitable for floodwater farming, but their large populations suggest that irrigation was required for their sustenance. It is not until about 400 B.C., however, that actual evidence of irrigation is available. The apparent importance of irrigation on the valley bottoms is shown by changes in both settlement and subsistence patterns. Over time there was a gradual movement of settlements to the margins of the valleys, away from the productive land along the rivers that could be readily irrigated. The notable changes in subsistence in the interval from about 1800 B.C. to the early centuries A.D. are the addition of a number of cultivated crops including maize, potatoes (*Solanum tuberosum*), polymnia (*Polymnia* sp.), common bean, manioc (*Manihot esculenta*), and avocado (*Persea americana*), the addition of domesticated animals (llama and guinea pig), and less dependency on large sea mammals. In the latter part of this sequence the early irrigation systems, which were of modest extent and located near the heads of the valleys, were expanded greatly to bring water to all of the arable land of the valley bottoms and outward toward the coast. This expansion has doubtless obliterated much of the evidence that once existed for the earliest irrigation systems. The impetus for such a rapid evolution of agricultural technology in coastal Peru seems to have been the introduction of highly productive and important crops, spurred on by a rapidly increasing human population.

The development of farming in coastal Peru seems to have involved first floodplain and floodwater farming along the immediate margins of the rivers. This was limited in scope and success by the amount of suitable land on the floodplains and attendant problems of salinization. Then the valley bottoms were brought under intensive irrigation and in some regions even the adjoining slopes were terraced and nourished with water from irrigation canals. Ultimately, there is evidence in some regions of inter-valley aqueducts to provide additional water for irrigation. Irrigation was hindered by the low flow of the rivers that occurred following the season of major runoff from the Andes, which occurs from January through March. The systems included facilities for collection, transfer, and distribution of water, but almost none for storage for use in seasons of low stream flow (Farrington, 1974). Thus, although farming could have been practiced year round, there was, as a general rule, only sufficient water to supply irrigation for a single crop.

A late innovation along the Peruvian coast was the practice of sunken-garden farming. These excavated gardens are found primarily in areas that were not irrigated but where the water table was naturally high or high because of irrigation in the vicinity (Rowe, 1969). Crops were planted one or two meters below the surface of the ground in the soil moistened by the high water table. There is evidence that these garden plots were constantly plagued by problems of

HP1271