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HENRY A. WALLACE
Secretary of Agriculture

HUGH H. BENNETT
Chief, Soil Conservation Service

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A QUANTITATIVE STUDY OF THE SUBTERRANEAN MEMBERS OF SOYBEAN

By HOWARD J. DITTMER [1]

A METHOD to facilitate the study of a plant's adaptability for erosion control was proposed by the writer three years ago.[2] Soil samples 3 inches in diameter and 6 inches deep were taken with a cutting tube, and counts and measurements were made of the included plant parts. These samples were found sufficient for making predictions as to a plant's soil-binding efficiency. The tool used for sampling was an iron pipe with an inside diameter of 3 inches and a tapered cutting edge to facilitate entrance into soil when driven with a heavy maul. Samples were taken of widely grown agricultural plants and counts and measurements were made of their subterranean members. Complete quantitative data of Kentucky bluegrass, oats, and winter rye also have been published.[3]

The soybean (*Soja max* Illini) was selected for this study because it is of great economic importance and is widely used in crop rotation even on fields subject to erosion. Soil samples similar to those previously mentioned were taken from a field under cultivation that had then been planted for its third successive year in soybeans. The yield was between 35 and 40 bushels per acre. The soil was carefully washed from the root members, and quantitative data were obtained through counts and measurements of the roots and root hairs. Table 1 gives the statistical data for the subterranean members of soybeans.

The taproot system of soybean is very poorly adapted for erosion control. Most of the branching is from 1 to 2 inches below the surface, giving the topsoil very little protection. The taproot has an average diameter of 2.5 mm. and this accounts for considerable volume but comparatively little exposed surface area for contact with the soil. The secondary roots, although not very numerous, expose more surface area than any other root division. Tertiary roots (those arising from the secondary members) were the most numerous and had the greatest total length. However, because of their small diameter, their surface area was smaller than that of the roots of the preceding category. Although they divide as far as the quaternary division, the roots of this category are exceedingly small; they average only 4 mm. in length and in all expose only 4.6 square inches of surface area.

Table 1.—Data showing totals for soybean roots and root hairs in a soil sample 3 inches in diameter and 6 inches deep (42 cubic inches)

ROOTS

Subterranean members	Total number of roots	Avage root length	Total length of roots	Average diameter of roots	Total root surface
	Number	*Millimeters*	*Feet*	*Microns*	*Square inches*
Main	4	120	1.5	2,500	5.6
Secondary	211	45	31.1	650	33.0
Tertiary	1,899	8	49.5	306	22.6
Quaternary	1,012	4	13.3	233	4.6
Total	3,126	.....	95.4	.....	62.8

ROOT HAIRS

Subterranean members	Number of root hairs per millimeter of root length	Total number of root hairs	Average length of root hairs	Total length of root hairs	Average diameter of root hairs	Total root hair surface
	Number	*Number*	*Microns*	*Feet*	*Microns*	*Square inches*
Main	0	0	0	0	0	0
Secondary	606	2,271,819	110	819	17	20.6
Tertiary	210	3,190,320	90	941	14	19.5
Quaternary	170	688,160	90	203	14	3.2
Total	.....	6,150,299	.....	1,963	.....	43.3

[1] Instructor of Botany, Chicago Teachers College, Chicago, Ill.

[2] Howard J. Dittmer: A Quantitative Study of the Roots and Root Hairs of a Winter Rye Plant (Secale Cereale). American Journal of Botany, July 1937.

[3] Howard J. Dittmer: A Quantitative Study of the Subterranean Members of Three Field Grasses. American Journal of Botany, November 1938.

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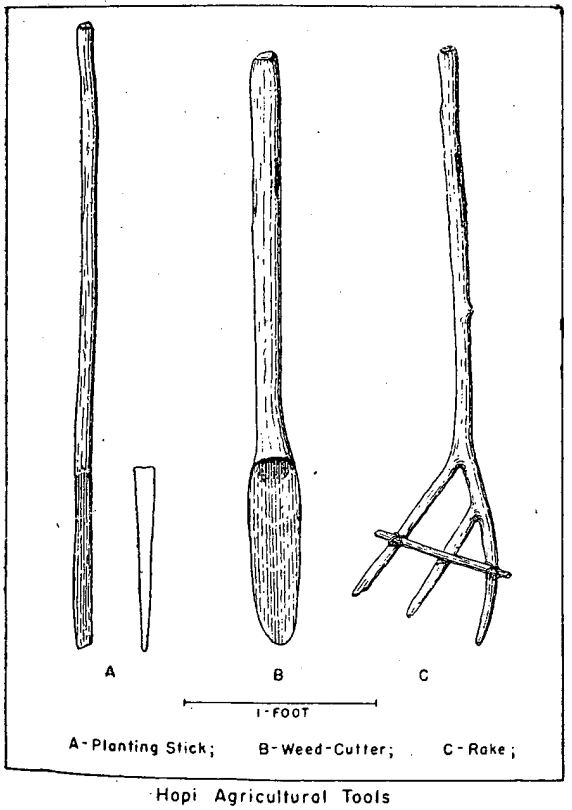
WATER CONSERVATION IN HOPI AGRICULTURE

By GUY R. STEWART and ERNEST A. NICHOLSON [1]

IN recent years agricultural agencies have become greatly interested in methods of conserving water and stabilizing crop and pasture growth in the drier portions of the Great Plains and the agricultural valleys of the West. In view of this, it may be helpful to examine some of the methods used for centuries by primitive cultivators of the Hopi villages of northern Arizona in their efforts to make a living in the less favorable parts of a semidesert region.

Although the Hopi are commonly considered members of the Pueblo group of Indian tribes, it should be noted that seven of the eight villages speak a language related linguistically to the neighboring Shoshonean tribes such as the Utes. Apparently the original Hopi came in contact with the Pueblo Indians at an early period and completely absorbed Pueblo culture with its traditional observances used to propitiate the powers believed to govern the success of crops in this arid land. Whether it is due to the remoteness of their location or to the devotion the Hopi felt for their acquired culture, they have been less affected than the Rio Grande Pueblos by contact either with Spanish explorers or with the influences of modern American life. The eighth village of the Hopi communities, Hano, located on First Mesa, belongs to the Tewa language group of the Rio Grande. These villagers took refuge at the head of the first mesa trail after the Pueblo revolt of 1680 and have continued to live there since that time.

[1] The authors are senior soil conservationist, office of research, Soil Conservation Service, Washington, D. C., and assistant soil conservationist, Southwest Region, Soil Conservation Service, Keams Canyon, Ariz.



Hopi Agricultural Tools

The three southern branches of Black Mesa, on which the Hopi villages are situated, are usually spoken of as the first, second, and third mesas. No records have been obtained of the precipitation on the higher portions of the northern mesa; but the relatively heavy growth of juniper and piñon indicate that it is materially higher than the 16-year average of 12.7 inches (4) reported at Keams Canyon, some 13 miles from the first mesa villages of Walpi, Sichomovi and Hano. The elevation of the Hopi villages on the first mesa is about 6,000 feet, while the agricultural land on the southeast and southwest is some 300 feet or more lower. In contrast to this the higher land on Black Mesa rises to a height of 7,000 to 8,000 feet, which probably accounts in part for a greater precipitation on the uplands.

This higher rainfall in the upper mesa country provides two important sources of water which have been utilized by the Hopi to supply part of their crops. The major part of the upland run-off finds its way into a series of streams heading in Black Mesa and flowing out on to the plains to the southeast and west of the mesa village lands. In addition, part of the upper rainfall forms a seepage of underground water that moves along the mesa top. The upper strata capping the rocky formations consist of relatively permeable sandstone which dips southward. The sandstone is underlain by compact shales and movement of water into the lower strata is extremely slow. Thus it is that the underground seepage moves along the shale beds until the junction of the two formations is reached some 50 feet above the base of the cliffs where the Hopi villages are situated. This gives rise to a series of springs that form a valuable source of water for the village terrace gardens.

There is no indication that the rainfall on the croplands adjacent to the three mesas is heavier than that recorded at Keams Canyon. Even were this light rainfall well distributed throughout the growing season,

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it would be insufficient for field crops such as corn and beans. The records, however, show enormous variation in annual precipitation which ranges from 5 inches in the driest years to 15 inches in the wettest. During most years there is a variable snowfall which has averaged about 27 inches, although it is doubtful that much of this moisture is effectively stored in the soil—this since the period from April through June, following the months when snow falls, is the driest and windiest of the year. Hence, evaporation is high during the period of planting and early crop growth. The most usual rains throughout the Southwest, especially during summer, are torrential thunderstorms of short duration and such as to produce rapid run-off.

These conditions point to the necessity for supplementing local rainfall by utilizing flood flow and underground seepage if crops are to be raised successfully. The methods developed by the Hopi in raising their staple crops of corn, beans, squash, melons, and peaches are based entirely on their own observations of local conditions and antedate any contact with white civilization. Success of the Hopi plantings depends upon the use of flood water run-off, as well as upon utilization of subsoil seepage areas and the development of terrace gardens on land adjacent to springs.

The greater part of the run-off from the higher mesa lands comes out in narrow streams which spread out over alluvial flats where the narrow canyons cutting the southern portion of the mesa give place to the flat valleys south of the Hopi villages. These lower lying valley lands may receive three or four floodings during June, July, and August. Since the flood flow is largely uncontrolled, water may at times stand to a depth of 5 to 6 inches until the excess is removed by evaporation and percolation into the subsoil. This shows one of the risks of flood water agriculture, for the smaller shoots of corn in valley fields may be drowned out by standing water. The fields along the sloping edges of the valley devoted to beans, melons, and squash depend upon run-off originating on the sides of the mesas.

In the lower flood fields an excess of water may wash out the corn where the current is excessively strong or may bury parts of the planted land under a heavy load of sediment. It appears probable, however, that risks such as these always have been a part of the systems of flood water agriculture practiced since early times. This is indicated by studies made by Mr. Nicholson, coauthor of this article, of the evidences of early agriculture found around many prehistoric sites. In addition, Dr. Ruth Underhill, (6), who has studied Indian irrigation among the Pima and other tribes, has concluded that most primitive irrigation tended to be of the flood water type, rather than systematic regular applications.

The observations on Hopi flood-water methods recorded in the following are based especially on the field studies of Mr. Nicholson who has worked in this portion of Arizona for several years. For the convenience of interested readers, references are made to several accounts that treat more generally of primitive agriculture in the Southwest.

The land devoted to beans, squash, and melons is on the more sandy soils along the lower edges of the mesas where local run-off from the mesa sides supplements the variable rainfall. Fields for these crops are found also on the upper mesas, near the peach orchards, where seepage from underground drainage makes cropping possible. Most of these lighter lands have brush checks placed across the fields, against the prevailing winds, to reduce soil drifting and prevent the young seedlings from being cut off at the ground level.

In addition to the two sources of water that have been discussed, the larger springs at the base of the mesas furnish irrigation water for several series of terrace gardens in which sweet corn, chile peppers, onions, and other introduced vegetables are raised with great success.

In general, the corn land lies in the valley flood-water areas where more productive sandy loams and clay loams may be found. In places, however, hills of beans are sometimes planted between widely spaced hills of corn, on the lighter soils.

No tendency toward any system of crop rotation has been noted. This agrees with the observations of Beaglehole (1), who found that each family usually planted the major portion of inherited clan lands to the same crop each year. Forde (2) (3) has mapped the distribution of the various clan fields in the cultivated areas adjacent to First Mesa. The point of special interest in this connection is that each clan possessed land in several separated parts of the village fields. Hence, the chance of complete crop failure for any group of families from an excess of flood water, destructive wind, or a local concentration of cutworms was greatly reduced.

It was observed that prevailing winds from the southwest tended to blow away the lighter surface soil from the western side of many of the fields on the lighter soils. This caused a gradual shift of land use, as the cultivator often moved the border of his area some yards to the east each year. Finally a time would come, after a field had been cultivated for a period of years, when most of the lighter fractions of surface

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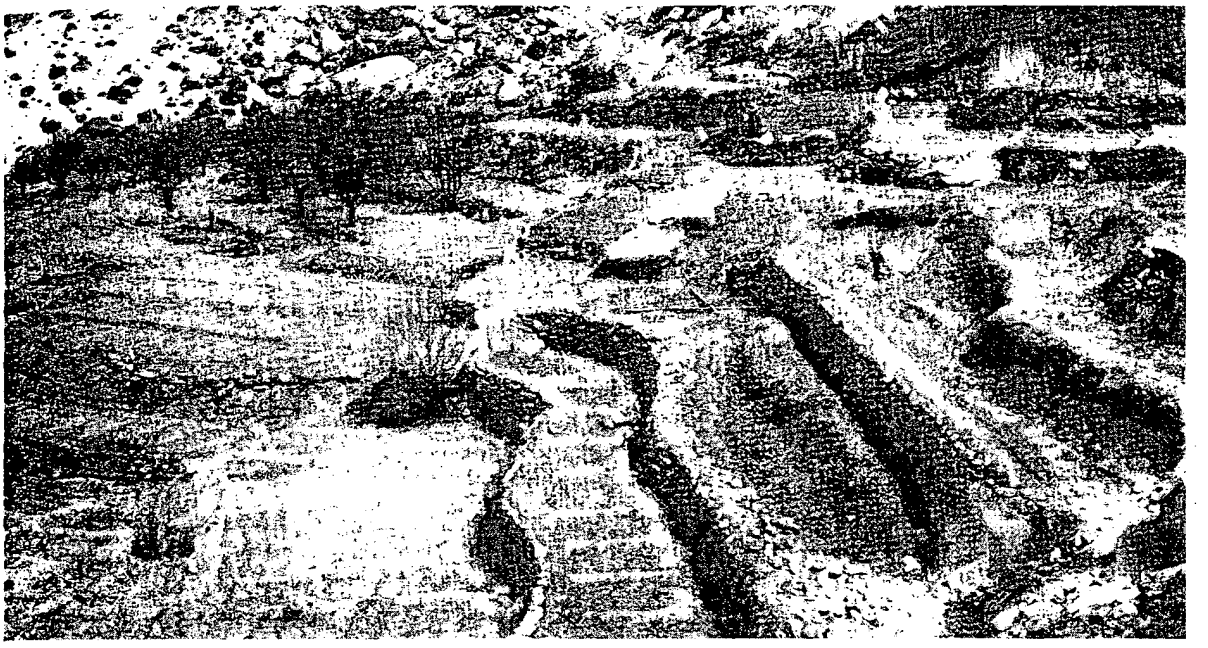

Hopi terrace gardens supplied with water from Wipo Spring, First Mesa.

soil would be removed. Such a field then would be allowed to grow up to weeds and small brush. After a few years, sufficient silt and fine sand might be intercepted by this cover to permit that moisture be retained in the subsoil and the land be returned to cultivation. This process has gone on for many years. The line of soil blown away tends to form a definite dike extending out from the field border. The authors have noted this sign of early cultivation in a number of places in the Hopi and Zuni country where other evidences of human use have disappeared.

The preparation of the fields for planting is extremely simple. This work starts in late February and is completed at intervals during the spring period. Because of the danger from wind erosion when the soil is excessively pulverized, the plow has never been favored by the Hopi cultivator. Many men still cling to the use of the primitive wooden tools described by Hough (5) and shown in the accompanying sketch. Weeds and brush are removed either by the digging stick (A) or the wooden pusher hoe (B). Latterly some of the Hopi have adopted a heavy steel hoe for digging out weeds and cultivating the soil. Each family ordinarily prepares its own land by chopping off the weeds with the hoe and removing small brush by prying it out of the ground with the digging stick. Brush fences and windbreaks are rebuilt on the lighter soils where crops other than corn are to be raised. Any available type of brush, or tree branches, may be used for this purpose. The same windbreak material will be allowed to stay in the ground even after it is defoliated, so long as the branches give some protection against wind action; but from time to time the low hedges will be reinforced when necessity arises. In the melon and bean fields the old roots will be removed as part of the land preparation, but in corn land the corn stumps of the previous year will be allowed to remain in the ground as a guide in order that the corn will not be placed in the same spot, and thus there is an alternation of planted area within the same fields.

Planting may start in late April or early May, depending on the season. On the first mesa, Beaglehole (1) reported that a series of nine ceremonial planting dates were fixed for the different crops. No such sequence has been noted on the second mesa. Here the villagers reported that each man observed the sun for himself and determined when the season was sufficiently advanced for the early crops. Watermelons are usually put in the ground first and followed by beans and early ceremonial sweet corn. The planting of the main corn crop does not start until the town crier announces that corn will be planted for the town chief 4 days later. The planting procedure is an interesting combination of mystical observance and sound agricultural practice based on long experience.

When the working party is assembled to plant for the town chief the men gather together for a ceremonial smoke and to breathe prayers for rain. Prayer sticks are placed before a field shrine and a handful of corn meal is sprinkled in the six major directions. After

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the proper observances, the planters line up along the side of the field, so that each will plant some three to five paces apart. The rows are spaced in between the rows planted the previous year and the hills are staggered in each adjoining row so that no hill is opposite another nor are hills planted in the same spots as in the previous year.

Each planter clears away the surface soil with his foot and then digs a trough-like hole from 12 to 16 inches deep. The damp subsoil in the bottom of the hole is loosened and from 10 to 20 seeds are planted and covered to a depth of 8 to 10 inches. This deep planting enables the plant to obtain the maximum benefit from the stored soil moisture and develop a root system that will resist wind or excessive floodwater. The planting of a large number of seeds permits development of a leafy clump of stalks which protects the center stalks from damage by high winds. The excess seed also provides sufficient plants so that a stand is likely to be obtained even though mice or cutworms may invade the field. As soon as the corn sprouts, the soil about the hill is kept loose with a digging stick and weeds are removed with a weeding hoe. If the hill is in an exposed position it may be protected by a small brush fence or by circles of protecting stones. In many instances the hills are surrounded by low banks of earth to retain rain or floodwater.

The planted crops receive considerable attention during the early period of growth. Mice and rodents are trapped and cutworms are picked off by hand. Portions of the fields which fail to receive floodwater are leveled off or roughly trenched to promote a more even flow. Additional small windbreaks are constructed to protect squash, melons, or beans which are found to be exposed to the prevailing winds. Weeds are cut with a hoe so as to conserve moisture during the time of most rapid development of the crop.

In the early period of Spanish settlement the Hopi acquired peach trees either from the missions or by trading with the Rio Grande Pueblos. Since that time the cultivation of this fruit has had an important place in the Hopi agricultural practice. Observation on the part of the Hopi orchardists showed that the seepage from springs and from underground water gave a supply of subsoil moisture adjacent to the mesas which was adequate for tree growth. Although there are a few budded trees on the mesas most of the new plantings are native peach seedlings. The fruit from these seedling trees is practically all freestone and though small, is excellent for drying. The peach trees are raised from seed, or cuttings, which replace the older trees as they pass their productive period. The young trees require careful attention and often need to be watered by hand until they are well established. The trees are planted by individuals in common village lands or clan fields and belong to the person who sets out and tends the tree.

Summary

Hopi agriculture constitutes an interesting combination of traditional ceremonial observance and sound conservation measures well adapted to semidesert conditions. Floodwater irrigation is the basis of crop production. The source of this floodwater is partly the run-off from the higher land of Black Mesa and partly local run-off which supplies small fields at the base of each mesa. Permanent springs supply water for a series of terrace gardens which produce chile peppers, onions, early corn and green vegetables.

(Continued on p. 51)

Brush checks, Second Mesa, recently put in to stabilize sandy land.

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Table 5.—Average time and fuel used per acre in seeding small grain by broadcast method, using tractors and horses on 9 contour- and 5 noncontour-farmed fields

Operations	Man labor per acre		Horse work per acre		Fuel used per acre	
	Contoured	Noncontoured	Contoured	Noncontoured	Contoured	Noncontoured
	Minutes	*Minutes*	*Minutes*	*Minutes*	*Gallons*	*Gallons*
Broadcasting	13.8	13.2	27.6	26.4	.....	.....
Disking	20.3	19.8	.....	.....	0.47	0.52
Harrowing	9.2	10.1	.....	.....	.22	.24
Total	43.3	43.1	27.6	26.4	.69	.76

Table 6.—Average time used per acre in seeding small grain by the broadcast method, using horses as the source of power on 13 contour- and 11 noncontour-farmed fields

Operations	Man labor per acre		Horse work per acre	
	Contoured	Noncontoured	Contoured	Noncontoured
	Minutes	*Minutes*	*Minutes*	*Minutes*
Broadcasting	13.8	13.2	27.6	26.4
Disking	37.2	43.9	168.1	198.2
Harrowing	20.0	17.4	80.0	69.6
Total	71.0	74.5	275.7	294.2

grain by broadcasting with an endgate seeder and followed up with a disking and a harrowing operation.

Although some variation was evident in the efficiency of performance among the individual operators, the data presented in the preceding tables indicate that less time and power were used for contour operations than for up-and-down-hill operations in the Plum-Beaver soil conservation district. The relative amounts of these savings may be ascertained by comparing the height of the bars in the accompanying chart. The performance on the up-and-down-hill farmed fields is represented as the standard, or 100 percent.

While the economies effected on contour-farmed fields in man labor, horse work, tractor and equipment use, and tractor fuel are not very large for the individual operator, they are of sufficient importance to merit the consideration of every farmer who is interested in increasing his efficiency and economy of operation. The implications of this reduction in time and power requirement are that farmers who adopt contouring as a part of their farming system are in a better position to (1) improve their timeliness of operations having seasonality, (2) increase their productivity, and (3) reduce their costs of production. However, due to severe drought conditions in this district during the 1939 crop season, evidence is lacking of the advantages gained from increased productivity due to timeliness of operation. Data obtained in this district in other years do indicate that crop yields were slightly higher on farms where the recommended practices were followed, and that the yields decreased with an increase in erosion. Since the cost of production up to harvest for the crops studied is not affected by the yield, it is safe to conclude the existence of an economic advantage in contour farming, even with the same yield, because of the saving in both labor and power when compared with up-and-down-hill farming. Any increase in yield resulting from contour farming would add still more to its economic advantage.

STRIP CROPPING

(*Continued from p. 38*)

deep on the highway at the lower edge of the field. It was impossible to estimate the amount of soil that was washed down the creek. Incidentally, the two tracts had been operated as one farm until 1937; hence, previous management methods would not account for the difference.

From a demonstrational standpoint, that one rainstorm did more good than a hundred speeches. The men at the Carlisle camp suddenly found themselves unable to cope with the flow of requests that came in for assistance in laying out strips. The energetic county agent did what he could, but he too fell behind in his work.

Thus Bourbon County farmers initiated their own soil-conservation program. Several of them began contour farming and strip cropping before agreements were signed. One noncooperator bought a field level like the one used by the camp and laid out contour strips on his five farms. Farmers in nearby Mason County, seeing the spread of strip cropping, hired their own engineers. Meanwhile, with every cropping season and every rain, the land of burley and the land of thoroughbreds is rapidly becoming the land of contour strip cropping.

HOPI WATER CONSERVATION

(*Continued from p. 48*)

Simple brush windbreaks have proved an important aid to the protection of crops of beans, melons and squash. The measures now employed in the Hopi country are suggestive of methods which probably prevailed among the Pueblo villages in the primitive agriculture of the Southwest.

(Editor's Note.—Literature citations were omitted for lack of space. Inquiries regarding source material should be directed to Dr. Stewart.)

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