SCIENCE

VOL. 81 FRIDAY, APRIL 5, 1935 No. 2101

SCIENCE: A Weekly Journal devoted to the Advancement of Science, edited by J. MCKEEN CATTELL and published every Friday by

THE SCIENCE PRESS

New York City: Grand Central Terminal

Lancaster, Pa. Garrison, N. Y.
Annual Subscription, $6.00 Single Copies, 15 Cts.

SCIENCE is the official organ of the American Association for the Advancement of Science. Information regarding membership in the Association may be secured from the office of the permanent secretary, in the Smithsonian Institution Building, Washington, D. C.

FACING THE EROSION PROBLEM[1]

By H. H. BENNETT

DIRECTOR, SOIL EROSION SERVICE, U. S. DEPARTMENT OF THE INTERIOR

THE productive agricultural lands of the United States are being seriously impaired and even destroyed on a vast scale. The plant nutrients and the soil body itself are being removed from fields and over-grazed ranges at an ever-increasing rate under existing methods of unwise land usage, with the effect not only of impoverishing and even destroying the uplands but of covering fertile lower slopes and productive alluvial plains with poor subsoil material washed out of the hills. Moreover, the products of erosion are filling stream channels and costly reservoirs; increased runoff from soil-stripped, gully-riddled slopes is increasing the hazard of floods; and many streams muddied with silt and colloidal clay have been deserted by valuable species of fish. This irreparable damage is increasing at an accelerated rate. Centuries would be required to build back the soil swept out of the fields and overgrazed pastures of the nation by this process that continues with every rain heavy enough to cause water to run downhill. We have been maintaining our agricultural production at the expense of the substance of the land.

The average citizen is unacquainted with the gigantic proportions of this devastating agency of uncontrolled erosion by wind and water. Educators, business men and statesmen, even our specialists—many of our engineers and agricultural experts—do not yet realize that more than 75 per cent. of the country consists of sloping land, all of which is subject to erosion in some degree where used for clean-tilled crops or where subjected to unwise grazing. Nor is it generally known that the average depth of the more productive topsoil of these erosive lands is only about 7 or 8 inches, or that this thin covering, representing the farmer's principal capital, is being swept

[1] Presented before Section O, American Association for the Advancement of Science, Pittsburgh, Pa., December 28, 1934.

completely away at rates ranging generally from about 3 to 60 or 75 years, depending on the kind of soil, the declivity of the land, the rainfall and the type of agriculture.

A thriving agriculture is the basis of national prosperity. When the rich, humus-charged surface layer is stripped off the land, it can not be restored, and without this productive covering agriculture generally can not be prosperous, whether prices are up or down. The world is strewn with ruins of once flourishing civilizations whose basis of continuance has been destroyed by erosion. No greater problem than the control of erosion confronts the nation to-day. The problem is national in character and scope. The injurious effects touch directly or indirectly the interest of every citizen.

White Man's Method of Land Use

What has happened in this country since the white man took over from the Indians the vast expanse of virgin soil, covered with far-flung forests of valuable timber or clothed with luxuriant prairie grasses, is a tragic story. Faster, probably, than any nation or race we have been impoverishing and destroying our indispensable agricultural lands. Other parts of the world, such as the highlands about Antioch, Syria, have been devastated by this wasteful process and the people have deserted the skeletonized areas, but their lands were used for thousands of years. We have used ours only a little more than 250 years, most of it for less than 75 years. In this short time we have succeeded in putting through a gigantic undertaking of land degradation, and this without stopping to think seriously of what we have been doing. Only recently have we begun to measure the impoverishing effects of erosion, and even now we have scarcely begun to apply the scrutiny of research to this menacing problem.

A short time ago it was estimated, on the basis of existing surveys, that at least 35 million acres of formerly cultivated land had been essentially destroyed by erosion. Now, on the basis of a nation-wide reconnaissance erosion survey, recently completed by the Soil Erosion Service, it is found that the area of formerly cultivated land largely essentially ruined amounts to not less than 100 million acres. This is the equivalent of 625,000 farms of 160 acres each, an area nearly equal to the combined extent of Ohio, Illinois, Maryland and North Carolina. Isolated fields and small parcels of ground between gullies and soil-denuded slopes can still be cultivated on a patch-farming basis, but fully half of the area is physically unfit for cultivation, chiefly because of severe gullying, with the other half about as bad.

In addition, approximately 125 million acres of the land now in cultivation have lost all or the greater part of the topsoil, and as the result these denuded lands are from about 2 to 10 times less productive than was the virgin soil.[2] They are not only less productive, but they are more difficult and expensive to plow and rainwater flows over the exposed impervious clay more rapidly to increase the rate of erosion, the rate of silting of stream channels and reservoirs and the volume of floods.

Thus we have permitted tens of thousands of farmers to become subsoil farmers, which means generally something very closely related to bankrupt farming on bankrupt land. Moreover, the virtual ruin of the soil is essentially of a permanent character, jeopardizing the well-being of generations to follow.

The Way Out

There is one way and only one way out of this menacing national situation of land depletion by erosion, and that is to put through as speedily as possible a properly coordinated, complete and adaptable soil-conservation program on all the remaining areas of good land needing protection. Such a program calls for treatment of the land in accordance with the specific needs and adaptabilities of the many different kinds of land. Any other method of approach will merely postpone the accomplishment of those things that must be carried through if this is not to be probably the greatest nation of poor subsoil farming of all the earth's history. Postponement of this inescapable task simply means a more difficult and costly job ahead.

We have been fighting erosion in some parts of the country for more than 75 years, notably in the southeastern Piedmont region; but we have not overcome the enemy. Even in this older agricultural section the evil has been spreading much faster than the application of efficient corrective measures. Our attack has been largely one in which a single implement was employed, that is, hillside ditching and hillside terracing for slowing down the runoff. On gently sloping land this single-track method of combat has accomplished much good, but on a very large area of steeply sloping, highly erosive soil the practice has, in the long run, done more harm than good. For example, the recently completed nation-wide erosion survey shows that considerably more than two million acres of terraced land in the state of Georgia alone have been essentially destroyed for further practical crop use. The building of terraces where they were not applicable, or failure to build them correctly and properly maintain them, hastened the permanent downfall of these formerly fertile slopes.

[2] H. H. Bennett, *The Geographical Review*, V. XXIII, No. 3, p. 431, July, 1933.

In spite of the obvious physical impossibility of controlling erosion except by making extensive use of vegetation in our control measures, many specialists to-day are boldly asserting that an engineering method of attack—one employing a single implement of combat—is the complete and final answer to the erosion problem. Since erosion begins wherever water accumulates in sufficient quantity to flow down hill across unprotected areas, the only possible purely engineering method for actually controlling an agency of this kind, if there is any truth in mathematics, would be to build extensive walls, as those found in parts of the Mediterranean Basin, with which it would be possible to cultivate the land on the level. Labor conditions and topographic and other physical characteristics of the land utterly preclude this method of control in America, for the present at any rate. Such laborious procedure is not essential to success; there are other methods—effective, practical methods, as those now being used with a high degree of success on the demonstrational areas of the Soil Erosion Service. These methods will be referred to later.

Need of Education

A depressing aspect of the whole erosion problem is that we have assumed the country has enough land to withstand the most violent misuse. Many have looked upon soil wastage by accelerated erosion as a process over which man has no control, and some have stubbornly refused to recognize any distinction between the exceedingly slow *geologic norm of erosion* (generally harmless) and the devastating *accelerated erosion* brought about through the instrumentality of man. With reckless prodigality, all kinds of land have been used for a great variety of crops, as if all of it, good and bad, steep and level, were equally adapted to these diverse uses.

The average American has no particular love for the land and little understanding of it. The explanation is fairly simple. Colonists pouring in from great reservoirs of population in Europe began a westward march across the continent under conditions that led them to believe the American continent was endowed with limitless and inexhaustible supplies of land, forest and game. Now that our frontiers have disappeared in the Pacific, and are reappearing in the East and West, we are beginning to appraise the gigantic waste that went with that rapid occupation of the country, which we have liked to boast of as the "conquest of America." Vast stretches of forest are gone, the buffalo have been killed, some species of game birds have been exterminated, and we find hundreds of millions of erosion-made gullies and tens of millions of acres of erosion-exposed clay subsoil where there was not a single gully of this kind nor one acre of man-induced, freshly exposed subsoil when the country was taken over by the white man.

It is true that erosion had been going on in many parts of the sparsely vegetated western regions, where great canyons had been dug out, before the advent of the white man. But we are not concerned with that phase of erosion, nor with the exceedingly slow process of normal or geological erosion, such as is responsible for the building up of fertile stream bottoms throughout millions of years. It should be perfectly understood that the accelerated erosion we are considering is the product of excessive runoff caused by the reduction of the absorptive capacity of sloping land as the result of removing the stabilizing cover of vegetation and the cultivation and grazing of the land since the occupation of America by the white man.

Absorption, runoff and erosion are interdependent processes, and for all practical purposes may be considered as a single 3-phase physical agency. These processes—rather, this agency is profoundly influenced by slope, climate, soil, density of the cover of vegetation and the use made of the land. When the normal vegetative cover is removed the soil is laid bare to the full destroying effects of violently rushing rainwater and hurtling wind. The process of plowing vitiates or tears down the effective porosity of the virgin soil, closing conduits made by earthworms and plant roots, and disrupting the porosity that goes with the natural granular or loam-like structure of the soil. With further cultivation the humus content of the soil—the sponge-like binding material—is dissipated by processes of decomposition and oxidation. In this way man effaces within a few brief years what nature has taken centuries, even thousands of years, to build. If we observe some of the lessons of nature, making liberal use of vegetation in various adaptable cropping practices and eliminating the steeper slopes from cultivation, these same areas can be conserved almost indefinitely. But we have not been thinking along these lines, and upon a foundation of misconception about the extent and durability of our good farm lands, plus a vast amount of stark ignorance concerning erosional processes and rates, and the dire effects of these activities on the productivity of the land, we have built a far-reaching system of farm tenancy which still further adds to the sinister import of this ignorance and indifference with respect to how the land is used and wasted.

Runoff and Erosion from Different Soils Undergoing Various Cultural Treatments

Quantitative measurements of soil and water losses from comparable areas undergoing different cropping treatments will be given for but one important agricultural soil.

Taking measurements made at the Bethany, Missouri, erosion station on one of the most extensive soils in the rolling sections of the corn belt (the *Shelby silt loam* and its very close relative, *Shelby loam*), it has been shown that from about the average regional slope (8 per cent.), devoted continuously to corn, the average annual soil loss from a representative slope cross-section of 73 feet has amounted to approximately 60 tons per acre, along with a loss of 27 per cent. of the total precipitation as immediate runoff. As against this, the corresponding losses from exactly the same kind of land, receiving the same rainfall, seeded to thick-growing, protective crops, have been very much less. Under alfalfa the loss of soil has been at the rate of only .21 of a ton per acre annually, along with a runoff of only 3.41 per cent. of the total precipitation; under timothy the corresponding losses have been at the rate of .32 of a ton of soil an acre and 7.74 per cent. of the precipitation. In other words—and this is of tremendous significance in connection with the whole national plan of flood control, land utilization, prevention of silting and conservation of our indispensable agricultural domain—alfalfa has been 289 times and grass 190 times more effective than corn in holding soil on the slopes where it belongs. The respective efficiencies of the two crops in relation to rainfall retention, as compared with corn, have been approximately 8 and 3½ times as great.

For the same period, the same type of land kept bare of all vegetation has lost an average of 112 tons of soil per acre per annum, or more than 500 times as much as was lost from fields devoted to alfalfa. From fields where a 4-year rotation of corn, wheat and clover was practiced—fields having exactly the same soil and slope and subjected to the same rainfall—the soil loss has proceeded at the average rate of only 9.9 tons an acre annually, while the water loss has been at the rate of 11 per cent. of the precipitation, showing that a good crop rotation is a highly effective method for minimizing both runoff and erosion.

These measurements indicate that under continuous corn production, on 8 per cent. slopes of this region, about 20 years would be required to strip off the top layer of productive soil, down to stiff, impervious clay that bakes in dry weather and sheds the rainfall at a terrific rate. On 4 per cent. slopes, approximately 30 years would be required to complete this job of surface denudation. Under grass something like 3,900 years would be required to remove the topsoil from 8 per cent. slopes of *Shelby* soil.

The *Shelby* soils, together with their closely allied types, constitute the principal kind of land within an area of about 11 million acres, in northern Missouri, southern Iowa, southeastern Nebraska and northeastern Kansas. Our surveys indicate that of this area about 4,500,000 acres already have suffered severely from sheet washing, and that 500,000 acres have been essentially ruined by gullying following sheet erosion.[3]

Damage of Valley Lands by Overwash of Erosional Debris

In numerous localities deposition of the products of erosion has had a disastrous effect with respect to channel choking, filling of reservoirs and covering of formerly good agricultural land with inferior soil material. Soil surveys in the Piedmont section of South Carolina had, prior to about 1930, classed 72 per cent. of all the alluvial land mapped within that area as *Meadow*—that is, as wet to swampy stream bottom so changed from the original condition by overwash that it was impossible to classify it correctly under definite soil type designations.[4] The stream channels had been choked with erosional debris, overflows were more frequent and most of the land, though formerly cultivated, had been abandoned, and supported a growth of willow, alder, sweet gum, smilax, blackberry, rushes and cattail. This is about the condition that now characterizes most of the alluvial soil of the entire Piedmont region from Virginia southward.

Soil types are being mapped in various parts of the country which represent recent wash from cultivated uplands. These soils generally are much lighter colored than the old alluvium which they have covered, and they are more diverse with respect to texture of material. Generally they are considerably lower in content of organic matter, especially where erosion of the uplands has proceeded to such an extent that relatively poor subsoil material is being deposited over the surface of the bottom lands. In this way some of these recently formed alluvial soils, that is, soils formed since the beginning of agriculture, represent an approximation of inverted upland soils transferred to the alluvial plains below.

Usually the line separating the buried pre-agricultural alluvial soil from that formed since the beginning of cultivation of the uplands is so sharp that it can be easily photographed. In many instances the depth of the soil belonging to the latter stage of deposition exceeds the entire depth of the old alluvium from its surface down to the bed of the stream channel or even to bedrock in some instances. Characteristically, the texture of the older material is distinctly finer than that of the recent

[3] H. H. Bennett, pp. 474–488, *Transactions, American Geophysical Union*, Nat'l Research Council, 15th annual meeting, 1934, Washington.

[4] H. H. Bennett, South Carolina teacher-training program (mimeographed), p. 20, Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, 1932.

deposits, darker colored and much more uniform. These facts, coupled with the fact that the covering of recent material often is as deep as and in some places deeper than that below, show conclusively that the characteristic suspension of the flood waters of the preagricultural stage was entirely different from that of the latter stage. Other profile characteristics, considered in connection with the obviously much longer period involved with deposition of the pre-agricultural material, show conclusively that sedimentation before the coming of the white man was from flood waters of comparatively slow velocity. Study of the profiles of these alluvial deposits in the older agricultural areas affords abundant evidence that floods along most of the streams within areas of rolling topography, as well as silting, have increased greatly since the beginning of agriculture.

Sedimentation of Reservoirs

Many of the storage reservoirs of the southern Piedmont have been filled to the top of the dam within less than thirty years. One major reservoir on the Colorado River in Texas was largely filled in the course of about five years. The Elephant Butte Reservoir in New Mexico, estimated in the beginning to have a life of 220 years, at the present rate of silting probably will be useless in times of protracted drought at the end of about 60 years. The Harding Reservoir in California filled as the result of one rainy period following a serious fire on the watershed.

Between 1922 and 1934 the watershed of the Gibraltar Reservoir (200 square miles), near Santa Barbara, California (the dam of which was completed in 1920), has, according to records recently made available, suffered from 11 major fires, which have progressively increased the area burned to 87 per cent. of the total watershed. Between 1920 and 1925 the silt content of the water entering the reservoir averaged .95 of one per cent.; this increased to an average rate of 1.8 per cent. for the period 1925–1931, and to an average of 2.9 per cent. between 1931 and 1934. The rate of silting for this 14-year period increased from 160 acre-feet per annum to 600 acre-feet per annum.

Practical Soil Erosion Prevention

Effective control of erosion primarily involves reduction of the soil-transporting effect of meteoric waters by those practical methods of land treatment which minimize the rate of off-flowage, thereby causing a larger proportion of the rains to sink into the ground at or near where they fall. These measures will be, principally: (1) Various adaptations of thick-growing vegetation to practical farm operations, (2) use of engineering structures and mechanical procedures where applicable, and (3) retirement of steep, excessively erosive land from cultivation. Our knowledge of the soils of the country, the topography, the rainfall, the types of agriculture and the rates of erosion and runoff from different kinds of land subjected to various cropping treatments and other uses is now sufficient to reveal finally and conclusively the physical certainty that until the distinctly different kinds of land are treated in accordance with their particular needs, as determined by the physical factors involved, it will be impossible to make any effective headway of a permanent nature against accelerated soil erosion, against the hazards of silting of stream channels and reservoirs, or against destructive floods within numerous drainage basins. These physically determined facts take the question outside the domain of opinion; and on the basis of this accumulated knowledge the Soil Erosion Service is proceeding as rapidly as possible, and for the first time in the history of the country, to put through large-scale, impressive demonstrations of erosion prevention and control, such as will show, and to a considerable extent already have shown, that it is practicable to control accelerated erosion by an integrated method of land treatment—that is to say, by using all known practical measures for minimizing the runoff from all the erosive land within a given watershed.

The Soil Erosion Service now has thirty-two erosion projects in thirty-one states, comprising an area of approximately twenty-eight million acres. There is immediate need for increasing these demonstrational projects to some fifty or sixty major areas, along with a considerable number of smaller outlying areas. By this it is meant that there should be complete demonstrations in those more important distinctive geographic regions of the country where erosion is known to be a serious problem and where the method of attack must be shaped to accord with differences in soil, topography, rainfall and agricultural practices.

The United States Debates and Delays

When we consider the fact that in some other parts of the world erosion is being effectively controlled by wise use of vegetation, cropping methods and engineering measures fitted, through integrated land-treatment programs, to the different kinds of land in accordance with their individual needs, it seems a pitiful situation that this great nation should stupidly pin the security of its agricultural domain upon a single method of erosion combat, namely, the use of engineering structures alone. When we see the descendants of the Incas giving almost complete protection to steep Andean slopes with rather simple methods of vegetative control and field arrangement, on land that was in cultivation at the time of the Spanish conquest about 400 years ago, it would seem that we actually

have much to be ashamed of in our record of disastrous land misuse. When we are told that Italy is spending $500,000,000 on her "Boniface Integrale" program of land conservation and reclamation, it would seem that those of us who have a real interest in the continuing welfare of the United States should be moved to action whenever those who know something of the subject assert that the nation can not afford not to spend now and in the near future whatever is necessary to conserve our remaining areas of good agricultural land. When we find that in parts of Germany much the same method of correct land use as that employed in the program of the Soil Erosion Service has been used for many years, and with a high degree of effectiveness and local satisfaction, in connection with their land programs, it would appear that there should be no undue concern on the part of any patriotic citizen if this program is markedly different from anything which has ever been tried in any important way in the United States. When we find Japan, in her program of protecting valuable agricultural lands, spending many times the value of those areas occupying erosive slopes for the purpose of protecting valuable tracts of lower land from the ravages of erosion and runoff descending from above, why should we be unduly concerned if in some localities it may be found necessary to spend in some instances as much as the land is worth in order to protect it, and thereby lower-lying areas affected by it—and at the same time give protection to stream channels and reservoirs from the erosional products discharged from such critical areas?

Flood Control and Silt Prevention

When it is considered that quantitative measurements of erosion and runoff from 12 extensive and highly important types of agricultural soil scattered throughout the country show that grass and similar thick-growing crops average 65 times more effective with respect to soil conservation and cause five times as much of the rainfall to sink in the ground at or near where it falls than on the same types of soil occupying the same degree of slope and receiving the same amount of rainfall, but devoted to clean-tilled crops, no further argument should be necessary to convince any thinking person that by bringing these densely planted crops more generally into use on the more erosive areas it will be possible to bring about some close approximation of permanent flood control and a large reduction in the hazard of silting of stream channels and costly reservoirs. Conversely, it should be clear enough to any one that until this is done—until we strike at the critical points of accelerated runoff from cultivated and overgrazed slopes, from the very crests of ridges down across watersheds where floods really originate and silt loads are picked up—we shall never have any very close approximation of permanent flood control or any important reduction of the hazard of silting, within many drainage basins, at any rate. On the basis of accumulated information, it appears entirely practicable to bring about that degree of erosion control and prevention—which really means control of the runoff—over most of the crop lands of the nation and over much of the grazing lands. It appears quite possible that this work, which must be done some time regardless of the inclination of any one, would result generally in something like a 25 per cent. reduction in the volume of floods, with perhaps greater reduction in some drainage basins. If this appraisal of the possibilities of erosion control is correct, then we can in a practical way bring about adequate flood control and a tremendous reduction in the costly filling of stream channels and reservoirs.

The Path Ahead

The course that the nation must pursue if this is to be a permanently productive agricultural country seems clearly marked out. If we refuse to conserve our agricultural lands, obstinately continuing with old methods that have failed, then we may as well confess that we have consciously chosen to head straight in the direction of land disaster. Since posterity can not meet the task and since many farmers are unable to handle all phases of the work that must be done, the responsibility of the government is obvious. Aside from this responsibility, the government has a very definite and inseparable interest in the continuing welfare of its remaining areas of good agricultural land.

PRESENTATION OF PROFESSOR JULIUS ARTHUR NIEUWLAND, C.S.C., FOR THE AWARD OF THE AMERICAN INSTITUTE MEDAL[1]

By Professor MARSTON TAYLOR BOGERT

COLUMBIA UNIVERSITY

"WELL, Father, now that you have taken so much trouble to show me all through your laboratories and explain so fully the conditions under which your research work is carried on, I am more than ever impressed by your splendid record of achievement!"

"Oh!" he said, in his characteristically modest way, "you overestimate what little I have been able to

[1] Hotel Astor, New York, February 7, 1935.