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# RESEARCH IN MECHANICAL FARM EQUIPMENT

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The increasing use of mechanical farm equipment during the past 80 years has developed production problems not unlike those of other industries. In less than a century the volume of production per agricultural worker has increased threefold, largely through the use of labor-saving farm machines. The substitution of power for muscular energy has lightened the physical tasks of farm life, but the problems of operating technic and management incident to machine applications have been materially increased.

So exacting have become the requirements of mechanical farm equipment, to meet the demands for quality and quantity production at low cost, that it is no longer possible to make satisfactory progress by rule-of-thumb methods. The equipment factors in agriculture—as in other industries—must be determined by scientific analysis. This will require study conducted in close correlation with the investigations of other agricultural factors which for many years have been the subject of research in agricultural experiment stations. Such research is essential, not only for the benefit of the farmer, but also for the aid and guidance of the farm-equipment-manufacturing industries.

The survey of the past two years, conducted under the direction of an advisory council appointed by the Secretary of Agriculture, has been for the purpose of determining what are the pressing research problems in connection with mechanical farm equipment and of formulating methods of attacking them through the established research agencies of the States and the Federal Government. This report relates primarily to the second year of study of this problem. It is supplementary to a mimeographed report prepared by J. B. Davidson and issued in December, 1926. The combined studies of 1926 and 1927 have emphasized the need of certain phases of mechanical farm equipment research in experiment stations if these agencies are to keep abreast of the demands of an advancing development in agriculture.

# PERSONNEL OF ADVISORY COUNCIL[1] ON RESEARCH IN MECHANICAL FARM EQUIPMENT

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E. W. Allen, Chief, Office of Experiment Stations.
S. H. McCrory (chairman), Chief, Division of Agricultural Engineering, Bureau of Public Roads.
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[1] Appointed by the Secretary of Agriculture, May, 1925.

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By H. B. Walker, *Senior Agricultural Engineer, Division of Agricultural Engineering, Bureau of Public Roads*

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## INTRODUCTION

This report is supplementary to the report, Research in Mechanical Farm Equipment,[1] prepared in 1926 by J. Brownlee Davidson,[2] Senior Agricultural Engineer, Division of Agricultural Engineering, Bureau of Public Roads. The earlier report gave the history and object of the survey, together with a list of over 400 suggested research problems in mechanical farm equipment. The research work in progress in 1926,[3] was reported also. No attempt is made in the present report to enlarge upon the general need for mechanical farm equipment research in the development of the industry of agriculture or the relationship of such investigations to the welfare of those en-

[1] Davidson, J. B. research in mechanical farm equipment. 93 p. Washington, D. C. 1926. (U. S. Dept. Agr., Bur. Pub. Roads.) [Mimeographed.]

[2] Professor of agricultural engineering, Iowa State College, on leave with the United States Department of Agriculture to serve as director of the mechanical farm equipment research survey, Jan 1, 1926, to Oct. 1, 1926.

[3] Prepared by R. W. Trullinger, agricultural engineer, Office of Experiment Stations, United States Department of Agriculture.

gaged in the production of our raw products for food, shelter, and clothing. The Davidson report[4] pointed out rather definitely the general importance of this field of study, and stated that many directors expressed the opinion that they would look with favor upon a way to open up investigation in this field.

The advisory council at its meeting in November, 1926, decided that further study and investigation were necessary to put into effect a national cooperative and correlated program of research in mechanical farm equipment. The council, accordingly, recommended the temporary appointment of a director to conduct these additional studies. H. B. Walker, professor of agricultural engineering, Kansas State Agricultural College, was appointed by the Department of Agriculture to direct this work for one year beginning March 1, 1927. Since that date the director has visited 39 land-grant institutions and has interviewed 262 staff members of these institutions. These included 6 college presidents, 31 directors and vice directors of experiment stations, 34 agricultural-college deans, 12 engineering-college deans, 115 staff members of agricultural-engineering departments, 28 agronomists and farm-crop specialists, 12 animal-husbandry and dairy-industry men, 14 agricultural economists and farm-management workers, 6 horticulturists, 5 entomologists, 4 poultrymen, 3 botanists and plant pathologists, 3 home-economics workers, and 2 agricultural journalists.

In addition to visits to land-grant institutions, the director also visited 31 industrial organizations having an interest in agricultural development. These included 19 farm-machinery companies, 5 pump companies, 3 cotton-ginning-machinery companies, 2 electrical manufacturers, and 2 public-utility companies. At these commercial plants 82 industrial officials were interviewed, including 14 presidents, 12 vice presidents, 26 general and sales managers, 18 engineers, and 12 advertising managers.

The director has attended during the year 15 meetings and conferences with technical engineering groups, scientific societies, and commercial associations. Numerous conferences have been held with Government research workers and others interested in the development of programs of research in mechanical farm equipment and related fields.

The information gleaned from the Davidson report,[5] together with that obtained during the year from visits to colleges and industrial plants, attendance at technical meetings, and personal conferences, forms the basis for the report which follows.

## SUMMARY AND RECOMMENDATIONS

The effort of the past two years has been one of survey and orientation in the field of research in mechanical farm equipment. This study has indicated the need of investigations in this field, and has pointed out types of projects on which efforts may be profitably expended at once. The general response from experiment station directors and other administrators interested has been favorable, and it appears that State and Federal funds may legally be used for the types of studies herein indicated.

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[4] DAVIDSON, J. B. Op. cit., p. 12. [5] DAVIDSON, J. B. Op. cit.

Already a majority of the States are conducting studies in mechanical farm equipment or related fields, and some expansion of this work is taking place from year to year. While problems, plans, equipment, and funds are important in the initiation and organization of such research, all of these seem secondary just now to personnel. Many more full-time, well-qualified research workers are needed to properly expand this field. To develop these is a task which can not be unduly accelerated. These workers are a product of personality, training, and experience in which mass production theories of development do not hold. While the development of personnel is taking place, however, it seems wise to coordinate these engineering studies very closely with investigations in related agricultural fields, in order to secure the benefits of research technic developed by more seasoned workers.

The problems of the future are not those of survey, orientation, nor promotion. The question now is primarily one of execution. It is the belief of the director that special investigations of a general nature are no longer necessary. The activities of the past two years have accomplished about all that can be profitably accomplished by such efforts.

The objectives of farm-equipment research in land-grant experiment stations have been adjusted in a broad sense to the general objectives of agricultural research. The actual execution of the research is the function of established agencies of which the following are important: (1) The State agricultural experiment stations; (2) the Division of Agricultural Engineering, Bureau of Public Roads, United States Department of Agriculture; (3) the Office of Experiment Stations, United States Department of Agriculture.

It is apparent that research studies involving the functions of farm machines can be most effectively conducted in the agricultural experiment stations, either in cooperation with or coordinated with other agricultural investigations. The agricultural-engineering staffs of these stations, operating under the supervision of the station director, should be able to function effectively with other agricultural investigators in the development of the end points of farm-equipment research as broadly outlined in this report.

The Division of Agricultural Engineering, Bureau of Public Roads, should accept with the States the responsibility for the execution of comprehensive research programs in this field. Its activities should be directed toward the coordination and solution of national, regional, and emergency problems. A large proportion of its work should be cooperative with the States. The guiding principle in such cooperation should be to round out the national and regional problems by offering technical help and financial support where it will be most effective for final results. In this way the division becomes a coordinating agency through its cooperative efforts. The development of a strong farm-equipment unit in the division is an essential feature of such cooperation. The relation of the division to other agricultural research agencies of the Federal Government should be similar to that recommended for the various departments of the State experiment station staffs.

The work of the Office of Experiment Stations is largely of an administrative character, involving both supervisory and advisory functions. In the development of comprehensive and coordinated research programs the assistance of this office in reviewing projects is essential for the maintenance of high standards of investigation. If the facilities of the Office of Experiment Stations could be enlarged to permit of more detailed review of projects, it would be the means of avoiding duplication of effort as well as of contributing to higher standards of research.

The suggestions herein made for the development of research in mechanical farm equipment are in keeping with the report (*1*)[6] on the agricultural situation by the special committee of the Association of Land Grant Colleges and Universities, which report was received at the forty-first annual convention at Chicago, Ill., in November, 1927, " and transmitted to the member institutions and to others, for consideration as a contribution toward the development of a national policy for agriculture." The following is quoted from this report (*1, p. 33*):

> The agricultural situation demonstrates the need of further agricultural research and of a broader education for the farmer and his family. Individual farmers, and most farm organizations, are not able to follow the methods of other industries in research and must largely depend upon nationally and state supported institutions. Programs of research carried on by these institutions should give growing attention to problems of land policies, marketing, farm incomes, costs of operation, consumptive needs, surplus production, and the standards of living of the farmer and farm laborer.
>
> Knowledge from these broad fields of investigation is necessary as a background for analysis of the problems of individual farms. Since the management of each farm constantly involves the direction of technical processes to secure the best result under the economic limitations encountered, the objective of agricultural research should be to supply such information concerning the operation of the farm as will enable each farmer to obtain the highest possible annual returns and at the same time to maintain agriculture in a prosperous and healthy balance with the economic activity of other industries. This implies providing information that will enable the farmer to select and combine wisely his crop and livestock enterprises, to select the best methods and practices in production, and to know the best time and place to market his products and the methods of marketing them. Attainment of this objective is possible only through possession of a fund of information that meets changing conditions and circumstances. It requires what may be considered as a continuous research service, made applicable to the particular conditions of various crop areas, and capable of interpretation by the individual farmer for application to his own farm.
>
> Since the establishment of the experiment stations and the research activity in the Federal Department of Agriculture, a large amount of research has been carried on. The results of this research, that sought to provide the basis for better methods of crop and animal production, are discernible in the improved practices of farmers. They have prevented the decline in producing power that would otherwise have followed the exhaustion of soil fertility, and the effect of disease and of insect and fungous attack. Science, through research, has opened many new opportunities to agriculture and in the field of production it has proven its value. This field of research needs further expansion and continued emphasis, that agriculture may have a constantly improving basis upon which to build its economic activity.

It is the recommendation of the director that the future development of research work in mechanical farm equipment be turned over to the established agencies of the Government and States with the recommendation that such research be developed along the broad general lines outlined in this report. In this connection it is further recommended that the advisory council be maintained to serve in a con-

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[6] Italic numbers in parentheses refer to " Literature cited," p. 42.

sulting or advisory capacity in matters regarding policy and methods of extending agricultural research into the field of mechanical farm equipment.

## EQUIPMENT INFLUENCES IN AGRICULTURE

A quarter of a century ago there was little direct engineering in agriculture. It is true the so-called machinery age in agriculture developed about 80 years ago, but the machines of that time were the product of the mechanic rather than of the engineer. Even yet, only a small proportion of the equipment of agriculture has been developed by technical analysis. The stimuli for progress in agricultural machinery utilization have come mostly from power transitions. The end of hand methods in farm production was characterized by the increased utilization of animal power. In the present century even greater changes are taking place in mechanical farm equipment—commonly known as labor-saving farm machinery—but the dominant factor in the present transition is the substitution of mechanical power for animal power.

This change is having a far-reaching effect not only upon the methods and efficiency of production in agriculture but also upon the standards of living of a people. Kinsman (*4*) states:

> Seventy-five years ago the average agricultural worker could care for but 12 acres of crops; now, considering the United States as a whole, he can attend to at least 34 acres and in some States where large power units are common the average is more than 100 acres, while on many individual farms it will run as high as 300 acres or more. At the same time the workers' hours have been considerably shortened and much of the drudgery and monotony of farm work has been eliminated.
>
> The increased efficiency in accomplishing farm work has greatly enhanced returns from farming and has released large numbers of workers from agriculture to other industries. This has resulted in greater production and a lower cost of comforts and luxuries, the enjoyment of which determines to a large extent the standard of living of a people. Undoubtedly these factors have played an imporant part in making possible the present standard of living of the people of the United States.

It is not unlikely that the early part of the twentieth century will be looked back upon as the mechanical power epoch in agriculture, just as 1850 is regarded as marking the end of hand production in farming. The mechanical power epoch, however, is more significant, since the applications of the internal-combustion engine and the electric motor have brought electric lights to farm homes, supplied water under pressure for the isolated farmstead, provided mechanical milkers for the dairy, and made possible many other labor-saving conveniences. In addition there are the great savings accruing in crop and animal production from the utilization of improved field machinery.

Thousands of acres of farm lands once considered marginal under hand methods of production are now supporting prosperous farmsteads, while other thousands of acres formerly yielding a family livelihood under hand methods of production are now marginal or entirely abandoned. Furthermore, these influences have resulted in marked population changes. In the early history of our Nation 90 per cent of our people were rural, while to-day less than 30 per cent are directly dependent upon the production of farm products. According to Gras (*3*) at the time of the first census (1790)

7 rural families had only one townsman to supply with food and raw materials, while to-day the 7 supply about 84 townsmen.

The change in ratio of rural to urban population, the opportunities for higher standards of rural living, and the necessity for increased output per worker, are reflected in the type of farmer now peopling our most desirable agricultural areas. Business methods have been introduced, and many of the problems of production are attacked on the basis of industrial analysis. The farm family enjoys the cultural facilities of the region in which it resides, and the rural standard of living—if apparently lower than that of the urban dweller—is due to lack of physical equipment rather than to human desire.

Volume of production per farm worker under the new régime is a factor of primary importance, but this must be attained at no sacrifice of quality and at no unusual exploitation of soil fertility. The present tendency in agriculture—as in other industries—is to operate on smaller margins per unit of production and to rely upon more units of production per worker. This practice has succeeded admirably in our manufacturing industries where centralized control is possible and where large units of production are placed under the management of our well-known "captains of industry." Moreover, such industries are able to attract to their staffs the best scientific minds of the country to analyze in well-equipped and adequately maintained industrial-research laboratories the various problems incident to production. Under centralized management these things are possible for research, development costs are readily allocated as a part of the cost of the finished product, and in the end both the producer and the consumer profit.

## EQUIPMENT PROBLEMS OF THE AGRICULTURAL INDUSTRY

The equipment problems of the farming industry can not be solved like those of other industries. Agriculture is necessarily a decentralized industry made up at present of more than six million units scattered throughout the Nation. These are engaged primarily in the production of raw products for food, shelter, and clothing, under variable conditions of soil, climate, crops, and transportation facilities. Moreover, some of the important markets for farm products are in foreign countries.

Even though different in organization from other industries, agriculture in North America has attained a preeminence without historical precedent. This has been due primarily to the use of more power per worker than is the case in foreign countries, and to applying this power to larger machines having more automatic features. Agriculture has accomplished these things with practically no research pointing toward farm-equipment objectives. It has, so far as practicable, copied the methods set up by other industries through systematic research. In these efforts agriculture has been admirably supported by those industries manufacturing the machinery utilized by farmers. Under these conditions our Nation has built up its agricultural supremacy. In comparison with our other industrial enterprises, however, this basic industry is somewhat behind in our national development. The facilities for a standard of living desired by our rural dwellers are not readily attained, owing both to lack of physical equipment and to insufficient income per worker.

The organization of the industry, based upon the family farm, practically precludes the idea of industrial research in agriculture such as is now so successfully employed in centrally controlled manufacturing industries. It is not to be expected that individual agricultural operators will establish their own laboratories for investigation and research in production problems. The individual farmer can not afford to do this and, moreover, there is no practical way of allocating the cost to his products even if he could afford to do it. The conditions surrounding the agricultural industry are fundamentally different from those of other industries in practical operation, but this does not necessarily imply that research in the equipment and production ends of agriculture is to be ignored or left undeveloped. In fact, if the lessons obtained from industrial research are of value, it would appear that the development of these phases of agricultural research are not only desirable, but essential.

## STATE RESEARCH AGENCIES FOR AGRICULTURE

The establishment of our State agricultural experiment stations gave agriculture the only exclusive research facilities the industry has even enjoyed. These stations have made invaluable contributions in the fields of plant and animal breeding, and in disease and pest control, soil fertility, and other related fields, but there has been but little organized research relating to the equipment used on the farm and in the farm home.

The adequate analysis of the equipment problems of agriculture introduces the use of an additional science into agricultural research. This is the science of engineering. Heretofore our stations have not been well equipped to undertake such work, owing to inadequacy of funds, personnel, and laboratory facilities. Moreover, the traditions of the institutions have made it difficult to harmonize the objectives of equipment research with those that have characterized agricultural research in the past. It should not be the function of the agricultural experiment station to do things that the agricultural or manufacturing industries can best do for themselves, nor should studies be made that will tend toward unnecessary paternalism through governmental agencies. There seem to be, however, certain types of equipment research which are peculiarly adapted to experiment station programs.

## THE OBJECTIVES IN EQUIPMENT RESEARCH

Farming to-day is more than the gaining of a mere livelihood. The typical North American farm family desires the same comforts and luxuries in life that are enjoyed by the urban classes. The farmer's motive for industry is to secure a better living, which includes, in addition to more desirable conditions of labor, better home and social conditions, such as educational facilities, opportunity for religious training, and active community spirit. The equipment for production is a means to an end in which other equipment and commodities secured through the exchange of surplus of production may contribute to the comforts and enjoyment of life. The equipment which will help the rural producer to accomplish these things most readily is the equipment agriculture desires. In selecting equipment for agriculture, the productive capacity of the worker must not be neglected, since lack of productive capacity upon the part of the farm worker may limit agriculture's purchasing capacity in the exchange of products with other industries which have greater productive capacity per worker and which produce the things rural dwellers desire in the maintenance of comparable living standards.

The agricultural producer must know with reasonable certainty that his equipment is suited to his operations. The increase in size of power units with the attendant increase in size of field machines has augmented the equipment investment per worker. It has also increased farm-management hazards; but on the other hand, it has enlarged the worker's vision of profits under capable management. This situation has put a new attraction into agriculture for men of more than ordinary intelligence; these leaders, however, must be supplied with definite knowledge on farm-equipment adaptability, duty, operation, and management. Should this technic of agriculture be developed by the exploitation of machines on individual farms, or does the farmer have a right to look to his laboratory—the agricultural experiment station—for equipment information and data, just as he does for data on the use of feeds which are developed through controlled feeding experiments, or for fertilizer data determined by extensive field studies? It would seem that agriculture, with no other laboratories for its direct benefit and guidance, does have some right to expect such assistance. Most of the other industries can do these things largely for themselves and then absorb the expense in the cost of their products; but for agriculture this is practically impossible.

## EQUIPMENT RESEARCH AND THE FARM-EQUIPMENT INDUSTRY

The development of equipment research in our experiment stations will be of service to those industries responsible for the manufacture of farm machines. In fact, the future of farm-machinery development depends upon analytical research, many phases of which can not be developed in industrial laboratories. The nature of modern industrial manufacturing is such that the farm-equipment industry can not resort in any great measure to the field-exploitation method of development. Volume of production in the modern manufacturing plant is of primary importance. Before volume in production can be assured, the product must be of proven value, with its commercial applications quite well defined.

In the case of some types of simple machines the factors which should be known in advance of production can be determined by laboratory studies; but in field-operating equipment such as new types of harvesting, tillage, and seeding machines, the factors of crops, soils, climatic conditions, and plant diseases may be important in determining the future value of the equipment. To prepare a factory for large-scale production without taking into account these agricultural factors would be financially hazardous, and if the products were exploited to the agricultural producer through short-sighted sales methods, the ultimate results might prove a menace to our agriculture.

It is true that the up-to-date implement factory should and does have experimental farms to test the operating characteristics and structural features of its products, but the determination of farm-machine requirements to meet special functions such as pest control, plant-disease control, fertilizer distribution, and similar situations, where the skill and scientific knowledge of the entomologist, plant pathologist or soils experts are necessary in addition to that of the engineer, is hardly within the scope of commercial research.

## EXPERIMENT STATION FUNCTIONS IN EQUIPMENT RESEARCH

Surely it is the function of the agricultural industry to specify certain fundamental requirements and principles for the equipment it should have to promote the most logical advancement of the industry. These fundamental requirements and principles must first be determined by basic research and then translated into practical farm utilization by experimentation and tests.

The ultimate objective of all research in agriculture is to bring about an agrarian development that will give the maximum of benefit to society as a whole. Research in farm equipment—which is a factor in this main objective—will be of direct benefit to two general groups: (1) Those who utilize farm machines and who must rely largely upon farm-machinery development for their industrial and social progress and (2) those who build or manufacture the equipment utilized in farm production and in rural life. In many ways the experiment station is the liaison agency between these beneficiaries of research, and its studies must be conducted under the same impartial analysis that has characterized all of our agricultural research heretofore.

Unquestionably, such research must be confined to developing such basic principles in equipment duty, application, operation, adaptation, design, and general requirements as can not readily be determined by the industries directly benefited. For example, it is evidently not the function of the experiment station to tell a farm operator just what particular equipment he should purchase to operate successfully his individual farm, but in these times of high initial machinery investments it does seem reasonable for the agricultural operator to expect the research facilities of his industry to determine the types of equipment best adapted to specific farm operations as, for example, machinery to be used for corn-borer control.

Again, it is not the function of the experiment station to build machines for the direct use of agriculture; rather, it should confine its efforts to a technical analysis of machine requirements in agricultural operations. So interrelated are the functions of machines with respect to the basic requirements of agricultural production that these things are practically inseparable. In the final analysis the machine becomes a means to an end in agricultural practice in which the machine may frequently be the control point in the initiation of a potentially better procedure. Likewise, the ability of the machine to meet the requirements as determined by scientific research has everything to do with its success as a commercial product. The final solution may be a compromise between a scientific requirement and a practical farm machine, but it is becoming increasingly evident that agricultural research will have a more and more important bearing upon future farm-equipment development.

## ENGINEERING RESPONSIBILITIES

Evidently in these problems the agricultural engineer dealing with investigations involving equipment must work in harmony with the agricultural scientist. Not only must he be sufficiently grounded in engineering science, but he must have a sufficient knowledge of the fundamental agricultural sciences to be able to comprehend the technical problems of the agriculturalist. He should then be able to translate these into practical operating terms for the benefit of the farmer and also for the benefit of the implement industry. The latter, in turn, should be able through its own organization to translate these requirements into terms of its specific products for the ultimate benefit of agriculture.

## THE 1927 PROGRAM OF RESEARCH IN MECHANICAL FARM EQUIPMENT

J. B. Davidson, as director of this survey in 1926, assembled over 400 questions and problems relating to research in this particular field. As a basis for the establishment of such investigations in State and Federal research agencies, the advisory council thought it advisable to prepare an outline of proposed research in mechanical farm equipment based upon the data assembled in 1926, and then to use this outline as a basis for encouraging research in this field during 1927. The outline approved by the advisory council follows:

### OUTLINE OF PROPOSED RESEARCH IN MECHANICAL FARM EQUIPMENT[7] IN 1927

[* Indicates projects to be actively supported by the advisory council]

A. Soil dynamics and tillage.
- *(*a*) Measurement of tilth.
- *(*b*) General soil dynamics.

B. Weed control.

C. Crop-production studies.
- *(*a*) Corn (machine methods).
- *(*b*) Cotton (machine methods).
- (*c*) Wheat.
- (*d*) Hay and forage.
- (*e*) Tobacco.
- (*f*) Fruits.
- (*g*) Cane.
- (*h*) Potatoes.

D. Harvesting studies.
- (*a*) Combine methods.
  - *1. Wheat, rye, oats, barley.
  - *2. Soy beans.
  - *3. Grain sorghums.
  - *4. Sweet clover.
  - 5. Rice.
- (*b*) Corn harvesting.
  - *1. Corn picker and other methods.
  - *2. Silage cutting and filling.
- (*c*) Cotton harvesting.
  - *1. Hand methods.
  - *2. Machine methods.

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[7] Adopted at meeting of advisory council held in Chicago, Mar. 10, 1927.

D. Harvesting studies—Continued.
- *(*d*) Hay harvesting.
- (*e*) Tobacco harvesting.
- (*f*) Fruits.
- (*g*) Cane.
- (*h*) Potatoes.

E. Grain and forage processing.
- *(*a*) Grain drying.
- *(*b*) Forage drying.
- *(*c*) Grain grinding.
- *(*d*) Forage grinding.
- *(*e*) Silage cutting.

F. Pest-control machinery.
- *(*a*) Corn-borer machinery.
- *(*b*) Central spraying plants.
- *(*c*) Spraying machinery.

G. Fertilizer studies.
- (*a*) Machines and methods.
  - *1. Combination fertilizer and seeding machines.

H. New Machines (or new applications).
- *(*a*) Stalk shredders.
- *(*b*) Combination fertilizer and seeding machines.
- *(*c*) Grain-sorghum harvesting machines.
- *(*d*) Sweet-clover harvesting machines.
- *(*e*) Cotton harvesting machines.
- *(*f*) Improved corn pickers.
- *(*g*) Corn-borer-control machinery.
- *(*h*) Soy-bean-harvesting machines.

I. Dairy equipment.
- *(*a*) Milkers.
- *(*b*) Sterilizers.
- *(*c*) Bottle washers.
- *(*d*) Drinking cups.
- *(*e*) Water systems.
- *(*f*) Milk coolers.
- *(*g*) Grinders.
- (*h*) Ventilators (Mechanical).

J. Water systems and pumps.
- *(*a*) Automatic household.
- *(*b*) Irrigation.
- *(*c*) Water softeners.

## TYPES OF PROBLEMS

The foregoing outline includes two general types or classes of problems: (1) Those of a fundamental or basic nature and (2) those relating to the application and economics of mechanical equipment used in agricultural production. Obviously these two groups of problems are interrelated. In general, the problems of the first group take precedence over those of the second group in most fields of research. The newness of the subject of equipment analysis in agricultural studies, however, renders the latter group more urgent at the outset than would be the case if such investigations had been under way for many years.

## BASIC RESEARCH IN MECHANICAL FARM EQUIPMENT

The advisory council, in considering the important problems of basic research in the equipment field, was guided by an analysis of the 400 equipment problems submitted in the Davidson report. It is apparent that it would be impracticable to organize and inaugurate a research program at the outset which would develop answers to all of the suggested problems. In fact, the solutions of many of the problems submitted are dependent upon finding a satisfactory solution of certain pivotal or basic problems, while other problems are of a nature to be most effectively studied in industrial laboratories.

Before technical knowledge can be most effectively applied to agricultural practices the "why" of doing things must be known. Studies which, by analytical process, tend to satisfy such queries constitute basic research. The design of the mechanical field equipment of agriculture, so far as it is directed toward the accomplishment of specific field operations, is based largely upon empirical methods. In any endeavor to apply scientific knowledge to agricultural practices and processes, one is confronted with the problem of fundamental relationships existing between the materials or products handled or processed, and the various elements composing the machine utilized in the operation. The success of present-day field equipment is a tribute to the ingenuity and judgment of our farm-machinery designers, but while they have not neglected the application of scientific knowledge in the construction of their machines, the objectives of design as to function have been to meet the requirements of current field practice. Undoubtedly many of the functions of farm machines which have been empirically determined through practice are sound in principle, but it is difficult to support these by factual material upon which technical analyses are made. To illustrate this point reference is made to the tillage operations in agriculture, which account for a very high proportion of the cost of crop production. Tillage has certain practical objectives—such as to improve tilth or to kill weeds. These are important, but to specify how best to attain these objectives is difficult. There is no measure for tilth values, and it is not certain that our existing field machines are controlling weeds with the greatest attainable efficiency. Before the definite function of machines in these problems can be determined, more must be known of the basic principles of weed control, and more definite methods must be devised for the measurement of tilth.

The importance of tilth in the field of mechanical equipment is indicated by the character of the problems submitted in the Davidson report. Out of 14 problems proposed in soil dynamics, 11 depend upon tilth values; 8 of 26 problems suggested for plow studies are dependent upon tilth; and 44 of 96 suggested problems relating to tillage machinery involve a broader knowledge of the principle of soil tilth. All field operations involve energy input, but with no measure of the thing to be accomplished, it is difficult to attain the objective or to measure the efficiency of accomplishment. These are matters which concern engineers responsible for machinery development since soil manipulation through machine methods is for the purpose of attaining specific conditions.

A better understanding of the properties of soils in their relation to the equipment used for farming operations is important. Some of the factors of interest in this connection are cohesion, adhesion, friction, compaction, shear, and soil liquids. The relations of these factors to one another within the soil itself, as well as to the elements of the machine coming in contact with the soil, have a very definite bearing upon the design and use of farm machines.

The council, in adopting tilth measurement, soil dynamics, and weed control, as basic problems meriting immediate attention, does not wish to convey the impression that these constitute the only basic studies needed, or that other problems submitted under the general classification of economic and application investigations should not include certain phases of fundamental research. These are, however, typical of the more abstract studies which, while not coming directly in the field of engineering research, are nevertheless essential in the development of agricultural machinery. They are typical of a class of problems which are distinctly experiment station problems, the solution of which will require research contributions from soil scientists, plant breeders, engineers, and others of the station staff.

To illustrate a method of attack on problems of this fundamental class, the director and M. L. Nichols[8] prepared jointly a general outline for a project on the measurement of soil tilth. This outline, which is included as Appendix 1, indicates an engineering approach to a problem involving assistance and cooperation from other subject-matter groups of the station staff. This is clearly a type of problem that can not be studied readily in commercial or private laboratories but it is nevertheless one of great importance to agricultural scientists, farm operators, and implement manufacturers.

## RESEARCH IN THE APPLICATION AND ECONOMICS OF MECHANICAL FARM EQUIPMENT

The application and economic problems suggested in the outline approved by the advisory council make up but a small percentage of the total listed in the Davidson report. Those suggested involve the application of existing and new machines to both production and processing of certain of our principal crops. Such studies must necessarily include economic investigations along with engineering analyses. In addition to equipment for crop production and processing, studies relating to pest-control machinery, fertilizer equipment, irrigation machinery, and dairy and household equipment, were thought to be worthy of encouragement.

The crop-production studies relate primarily to two of our principal crops—corn and cotton. The greatest economic distress in agriculture, following the war, has been in the corn and cotton areas. This period has been characterized by abundant production and low prices. The situation has stimulated interest in all types of farm machines which offer promise of saving labor, but at the same time it has developed a critical buyer of farm operating equipment. The farmer of to-day, with narrow margins of profit, is depending more and more upon volume of production. He must be certain of his methods. Accordingly he is asking more questions and seeking more information concerning the management, operation, use, and duty of his farm machines. He is looking to the experiment stations for this information to guide him in his production program.

The relation of mechanical equipment to corn production is worthy of analysis. Some of the mechanical-power equipment developed for this purpose is new and as yet not in general use in the Corn Belt. These new types of machines develop new problems in management,

[8] Agriculture engineer, Alabama Experiment Station, Alabama Polytechnic Institute.

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farm organization, machinery care, and operation. Careful study on the part of the stations will not only assist in developing facts of value to the farmer directly, but the incidental engineering studies should yield data useful to manufacturers.

Studies in cotton production and in processing equipment are also important. The competition in growing cotton—owing to the development of machine methods of production in the Great Plains area—has emphasized the place of mechanical equipment in this field. Already one station has issued a bulletin (*2*) on this topic. These studies, however, were confined to particular areas and involved investigations only up to the time of harvest. The cotton-harvesting problem is a subject for widespread study, and since methods of harvesting have an important relation to ginning processes, research in this latter field should be included.

Some of the methods of production now being successfully followed in the western cotton areas are so unlike those now practiced in the more traditional cotton sections that great changes in agricultural practices may be necessary to meet the new economic conditions arising. These changes must become a subject of study by our experiment stations. Even though our State experiment stations are free from commercial research they do assume to a marked degree, nevertheless, the responsibility of fostering and directing agricultural progress in their respective States. The necessity for research in machine methods of crop production in one section may be due to progress in some other area. This is a situation facing many of the older cotton-producing States.

The advisory council, acting through its director,[9] and cooperating with the research committee of the American Society of Agricultural Engineers and the farm machinery committee of the southeastern section of the same society, has prepared a general outline for a cooperative project in farm machinery for the Southern States. This outline is attached to this report as Appendix 2.

The demand for new information on grain and forage processing is particularly urgent. Problems in grinder types, power and labor costs of processing, quality of products, relative feeding value of ground and unground products, convenience of handling, storage requirements, and many others confront the farmer. The national interest in rural electrification[10] has stimulated unusual interest in the processing of farm crops, particularly as to grain grinding. These studies have already had an important influence upon the development of grinding equipment to meet the requirements of a type of energy that is comparatively new to the farm. This work has the hearty support of the council, but it is believed that the need for a greater number of detailed studies under carefully controlled conditions is now evident.

The increased demand for hay of higher quality—brought about largely through the growth of the dairy industry—has developed problems in hay drying which are attracting widespread attention.

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[9] The director feels that special acknowledgment should be made of the assistance rendered by M. L. Nichols, agricultural engineer, Alabama Polytechnic Institute, who as a member of both cooperating committees rendered valuable assistance.

[10] Studies of the relation of electricity to agriculture are being conducted in 23 States under the general sponsorship of the national committee on the relation of electricity to agriculture.

In the more humid areas artificial drying methods are of particular significance. To determine a practical plan for the processing of such farm products, many types of experimental work are essential. These include the palatability and feeding value of the processed hay, the factors underlying the dehydrating methods, the type of dehydrating plant best adapted to agricultural conditions, the effect of such methods on management, and many other problems of an agricultural and engineering character. In the less-humid areas studies in improved methods of hay harvesting using natural drying processes are needed. Although hay is an important crop in practically every State, very little organized thought has been given to haying equipment in its relation to production methods and costs.

The advent of the combine harvester in the winter-wheat belt with its attendant lowering of harvesting costs, has developed many prob-

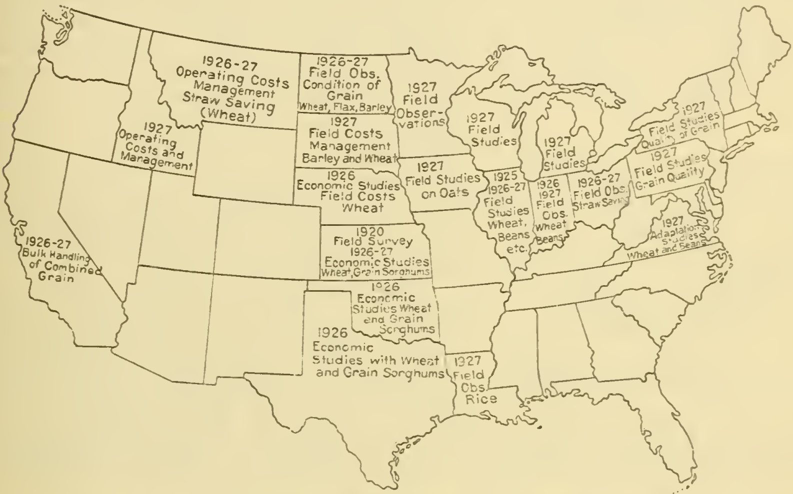


FIG. 1.—Combine-harvester studies in the United States

lems. Interest in these problems has arisen from economic necessity, with the result that 11 States and the United States Department of Agriculture conducted studies in 1926, and 15 States and the Federal department carried on even more extensive investigations in 1927. (Fig. 1.)

The control of crop pests is always an urgent problem. The invasion of the European corn borer is an illustration of such a problem. In this, as in the control of most crop pests, machinery is an important factor. The effectiveness of machinery in preventing commercial damage to the corn crop, however, would be greatly impaired or even valueless without the benefits of the research conducted by the entomologist, the agronomist, the plant breeder, and others whose field of study must form the foundation work for machinery control. On the other hand, the work of these scientists probably would be of much less practical value to the farmer if the engineer did not cooperate in developing machines to meet the requirements of field control as laid down by these scientists. This is an example of experiment station research in which there is a common aim—namely, the control of the corn borer—and in which is involved a pooling of scientific knowledge to attain this common objective. This relationship is well illustrated by the diagram on the cover page of the plan and program for European corn-borer research, 1928, United States Department of Agriculture.[11] This has been reproduced as Figure 2.

The problems of pest control involve not only the purely control measures but also economic management, correct farm organization, and the development of proper sizes and type of machines. The council's program for pest-control research in 1927 included, in addition to corn-borer-control machinery, central spraying plants and spraying machinery.

The use of commercial fertilizers ever grows more important as the agriculture of a region advances. The development of higher-grade fertilizers has brought corresponding problems in their application to the soil. In such studies the combined knowledge of the engineer and crop specialist is needed to determine the principles and requirements of fertilizer-distribution machinery. Studies of this general type are particularly timely in the north Atlantic and southeastern sections of the United States.

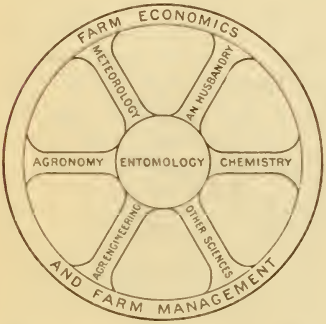


FIG. 2.—Plan and program for European corn-borer research, 1928

The council, in adopting a program to include new machines, felt that studies of such machines should be confined principally to those required for the development of the suggested program. In general, it appears more important to inaugurate studies which will tend toward a better utilization of existing machines than to study machines not now in use or having limited application. Simplification of farm machinery is particularly desirable. Moreover, all farm machines should be developed for maximum utilization. It is expensive to both the farmer and the manufacturer to retain a large number of machines with limited agricultural applications. Volume production of high-quality equipment having a wider agricultural application should result in more economical operating conditions for both the manufacturer and the farmer.

The research activities stimulated through the various State committees on relation of electricity to agriculture have included extensive investigations with dairy equipment, water systems, and irrigation pumps. A great part of this work has been centered on electric applications to existing machines and the tabulation of records of energy consumption. These data should lead to more exhaustive studies of the requirements of farm dairy and water equipment. In this connection the development of more laboratory research under carefully controlled conditions seems desirable.

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[11] UNITED STATES DEPARTMENT OF AGRICULTURE. PLAN AND PROGRAM, EUROPEAN CORN BORER RESEARCH, 1928. 71 p., illus. Washington, D. C. 1928. [Mimeographed.]

## STATUS OF PROJECTS AND PROBLEMS REPORTED IN 1926

The council, before adopting a program, considered carefully the Davidson report of 1926.[12] An analysis of the status of the problems and projects prepared from that report by the present director is included as Appendix 3. A considerable number of projects relating to subjects mentioned in the council's outline were already under way at the time of its adoption. Many, however, reported as under way were either inactive or were being prosecuted at a slow rate because of lack of funds, equipment, or personnel. For this reason the work on projects reported as under way appears more significant than it actually is.

### SOCIETY AND ASSOCIATION PROBLEMS

A considerable number of the problems suggested in the Davidson report relate to studies which most logically come within the province of technical societies and trade associations. The director assembled a group of these which are attached to this report as Appendix 4. Many of these already have been taken up by such organizations.

### NEW MACHINES

Another group of problems in the Davidson report relates to new machines. Experiment stations should be in a position to determine the functions and requirements of new machines where these are desirable for the advancement of agriculture. In this development, however, the building and distribution of equipment for commercial utilization belongs to industry, and the final development of the commercial product may take place in industrial laboratories. A list of the suggested new machines is attached as Appendix 5. In the development of new machines cooperation between commercial and State agencies may be justified if the machine is essential in the initiation of a farm practice having recognized potential merits.

### MANUFACTURERS' PROBLEMS

A third group was prepared under the classification of Manufacturers' Problems; many of these are concerned primarily with machinery design. These represent a class of problems which in many cases can be solved most effectively in the laboratories of the appropriate industries. The final checking of the application of certain devices may require field experimentation in connection with State experiment stations. These problems are listed in Appendix 6.

## THE EXPERIMENT STATION APPROACH TO FARM-EQUIPMENT RESEARCH

Conferences with agricultural experiment station directors in 1926 and 1927 disclosed an interest in research and investigation in mechanical farm equipment. The method of approach in the development of data for the benefit of agriculture, however, was not clear to all. The director, in interviews with experiment station directors and workers, made a special effort to develop a point of view on the following topics: (1) The logical approach to problems requiring

[12] DAVIDSON, J. B. Op. cit.

research in equipment; (2) the type of data to develop in equipment research; and (3) the relationships which are most desirable between Federal and State agencies cooperating in such research.

### THE END POINTS OF EQUIPMENT RESEARCH

The end points of research in agricultural equipment must be in harmony with the objectives of other experiment station research. While such research belongs to agricultural engineering, the most important consideration is not equipment but agriculture. Engineering development is only a factor incidental to the development of a greater and better agriculture. In equipment research quite often this relationship will determine the organization of a project. For example, the artificial drying of hay may require the most exacting engineering analysis before it becomes an economic practice; yet the real objective of a research project on this subject is to produce a hay of such superior feeding qualities that artificial drying methods may be feasible. The initial steps in such a project may involve a study of the physiology of the particular forage plant to be processed. This might be followed by chemical tests of the nutritive value of the product, and, later, feeding tests may be needed to determine the palatability and nutritive value for animals. In all of these studies the objective is to discover the relative value of artificially processed hay as compared to hay cured by natural methods. The determination of these factors, however, should be correlated with engineering studies to find out ways and means of dehydration, temperature tolerances, and other factors to meet the requirements of production as laid down by the cooperating investigators. The engineering analysis, in turn, may be influenced by problems of farm organization and management. In short, a project in the artificial drying of hay becomes a station project rather than a departmental one, in which the station staff representing many departments may be utilized in reaching a solution.

A number of State experiment station directors take the view that equipment, being incidental to agriculture, is not in itself an end point of research, but it should be studied in its relation to the agricultural end point, which may be butter, apples, wheat, hay, beef, or any one of numerous other farm commodities. If this method of approach is followed, the initiation of equipment projects should come through cooperative channels. Generally speaking, this is desirable since a combination of agricultural and engineering talent is required to make the best analysis of a farm method or process involving machines. In some respects such a plan, if rigidly adhered to, may tend to retard machine investigations, but this is unlikely since agricultural research has become so interrelated within recent years that most workers recognize the importance of the machine phases of investigations. It should be mentioned, however, that a commodity end point does not imply an immediate exhaustive investigation into every phase of the commodity. It may relate only to the harvesting of a crop, such as cotton. Here the study of cotton pickers is important both as a machine and as to its influence on the final product—that is, the spinning value of the cotton. Another example would be the washing of apples to remove poisonous residues from spraying. This is a commercial necessity requiring not only economical removal of the poison but also treatment to insure that the apple shall not deteriorate in value before it reaches its ultimate market. Frequently the major objective may be centered about a machine or type of equipment, but in such problems factors of economics and management may be involved which will necessitate the cooperation of the farm-management workers.

The relationships thus far mentioned are most applicable to problems involving the economics, application, and requirements of equipment in production. In some types of research, particularly those of a basic nature such as soil dynamics, these general relationships may not be necessary nor desirable.

In certain emergencies, like the invasion of the European corn borer, the attainment of the common objective of research—the control of the corn borer—may require the separation of the problem into various component parts with group relationships developed as the progress of the investigations may require.

### THE ENGINEER A TECHNICIAN

The function of the engineer in the agricultural experiment station is primarily one of technical service. The economist has a similar relationship. In the case of commodity investigations, these technicians are of service in contributing toward the end points of the project. On the other hand, an economist may rightfully conduct detached studies, such as taxation and land utilization, while the engineer may very properly study the mechanical efficiency and the fundamental principles of farm-machine design. It must be remembered, however, that the direct field of investigations for such technicians is restricted to an industry, and care should be exercised to avoid researches which may properly belong to similar technicians in other fields.

### FARM-EQUIPMENT DATA

Data obtained through farm-equipment research falls into two general classes: (1) That which relates to the function of the machine in production, and (2) that which applies directly to the machine itself. In obtaining data of the first class the assistance of the cooperating agriculturist is of primary importance, but the engineer must accept practically all of the responsibility in connection with data of the second class. In many instances these data will be developed through a common research; but their interpretation may in one case be based on the performance of the machine for a specific agricultural practice as interpreted by the agriculturist, and in a second case based on the performance of the machine with reference to its machine functions as interpreted by the engineer. The combined interpretations of the agriculturist and the engineer should enable each to specify more correctly the requirements of their respective tasks. Thus the engineer, knowing the requirements of the agricultural crop or product, will be able to specify the technical requirements for potential machines to carry out a new farm practice; while the agricultural cooperator, having a better knowledge of machinery limitations in the specific problem, will be able to adjust a farm practice, or produce a type of crop, to meet the practical requirements of existing or potential farm machines.

Fertilizer equipment may be used as an illustration. The agronomist through experimentation may determine that the highest efficiency from a concentrated commercial fertilizer is obtained when the materials are mixed into the soil and placed a specified distance from the seed at the time of planting. The strength of the fertilizer may be such as to require a very accurate distribution, and the studies of the agronomist may set up certain ideal conditions for the economical use of the commercial product. The existing distribution equipment may so fail to meet the requirements under field practice that the potential value of the product becomes dependent upon the development of a new machine or a modification of the practice to fit the present machines. The final determination is of importance to agriculture, to the fertilizer industry, and to the implement industry. If the engineer and the agronomist work together on the problem they should reach a solution which will define within reasonable limits the functions of a practicable field machine, the conditions for successful field operations, and the kind, type, and proper handling of fertilizer to insure satisfactory results. In these studies the interests of the fertilizer and implement industries should not be neglected and, in fact, the cooperation of industrial-research agencies should be sought. It is only through such correlated research that the solution of a problem can be attained and can be translated into improved practice that is of benefit to agriculture.

An important consideration in the development of data relating to the use, duty, requirements, operation, design, and care of mechanical farm equipment is that our equipment development is not static but dynamic. A review of the record of farm-equipment progress during the past 75 years bears out this statement. This progress has been due largely to the initiative and aggressiveness of our equipment industries. Competition within the industries themselves, coupled with individual initiative, should always serve as a stimulus for attaining industrial leadership. This is fundamental to our progress. The function of experiment-station research is more to give guidance and direction to equipment development to the end that agriculture shall be better served by better-adapted machines.

## RESEARCH RELATED TO EQUIPMENT

Operation and economic studies of farm machines may result in developing practices and methods of far-reaching importance. The introduction of the combine into the winter-wheat belt attracted wide-spread attention following field studies to determine the operating problems and field costs in wheat harvesting. The success of this harvesting equipment in the winter-wheat belt has led adjacent States to experiment on its adaptability to wheat and other crops under different climatic conditions. Crops other than wheat now harvested by the combine include oats, barley, grain sorghums, soy beans, buckwheat, rice, flax, and red clover.

A significant part of the investigation of the combine by the State experiment stations and the United States Department of Agriculture has been the studies in grain storage and drying. These have led to investigations on the relation of time of cutting grains to quality and yield. The Iowa station,[13] in connection with combine-harvester studies, found in its first year of study on relation of time of cutting to yield of oats (rust-resisting varieties) "that Iowa oats yield 10 per cent more at time of combine than at time of binder operation, and for a period of three weeks the yield continues to be equal to or greater than when put in the shock." Studies in Illinois (*5*) Indiana, and Virginia have shown the practicability of this type of harvester for soy beans, a crop which heretofore has not been widely grown because of harvesting difficulties.

The studies of the use of the combine in the humid sections have shown the need for straw-saving equipment, greater separator capacity, adjustable reels, and wider grain platforms. Several years ago the thought prevailed that power-takeoff-driven combines would be satisfactory for the smaller machines of the humid areas. The concerted studies conducted during 1926 and 1927, however, have shown that such designs are of doubtful practicability, a disclosure of great value to the implement industry. The thorough study made by the experiment stations has been the means of bringing about a type of combine best suited to farming operations in the humid areas.

## RELATIONSHIPS WITH FEDERAL AGENCIES

It is evident that many phases of farm-equipment research are of regional or even national importance. In the solution of such problems State and Federal cooperation will often be desirable. In addition to cooperation in specific problems, it would seem to be the function of Federal research agencies to accept the responsibility of acting as a correlating agency in all lines of research having more than State-wide importance. This is required where Federal funds are used for experiment-station work. The following is taken from an extract from an act making appropriations for the Department of Agriculture for the fiscal year ending June 30, 1923, and for other purposes (*9, p. 49*):

> * * * and the Secretary of Agriculture shall prescribe the form of the annual financial statement required under the above acts, ascertain whether the expenditures are in accordance with their provisions, coordinate the work of the Department of Agriculture with that of the State agricultural colleges and experiment stations in the lines authorized in said acts, and make report thereon to Congress.

This work is a function of the Office of Experiment Stations. Federal bureaus and divisions, however, may lend assistance through active cooperation by using their own funds and personnel. The manner in which these are used will affect the correlation of the work on national and regional problems. Federal cooperation should be considered from the standpoint of coordinating activities. Institutional or State initiative should not be interrupted, however. In fact, the approach to most research problems having national significance will be through the States, since these—through their experiment stations—are most likely to have facilities in the way of laboratories, farms, and equipment for use in studying the problems.

[13] MERVINE, E. M. COMBINES IN IOWA IN 1927. (Address by E. M. Mervine, Prof. Agr. Engin., Iowa State Col., before the Farm and Power and Mach. Div., Amer. Soc. Agr. Engin., Chicago, Ill., Nov. 28, 1927. Unpublished.)

In certain cases, such as emergencies, the Federal approach may be direct, but on the other hand independent Federal research within a State may tend to create jealousy between State and Federal workers and this often results in inefficiency. If two or more States are working on the same general problem, it may be desirable for the Federal agency to lend its cooperation only through the States having the best facilities for the particular research undertaken; or the Federal agency may, in furnishing assistance on particular phases of a problem, divide its cooperation by allocation among the several institutions. Such cooperation tends to correlate activities and promote efficiency. It also affords the Federal agency an opportunity to place its support where it will do the most good from a national standpoint, and with the least expense in equipping laboratories and farms.

It would seem to be self-evident that cooperation through Federal bureaus and divisions should not be extended to local investigations except in extreme emergencies. Their functions are national. They should do those things which State agencies can not do effectively by themselves. In these matters it would seem that the State workers may logically look to their respective Federal bureaus and divisions for assistance in determining the status of research problems. This should include information not only from national but from international sources as well.

In the field of mechanical farm equipment many problems of national importance require research. The corn-borer studies afford an example of emergency research in which national leadership and guidance are highly desirable. The combine studies in which Federal cooperation was extended is an example of a regional problem being studied through State initiative but with Federal guidance. The cotton-machinery studies are of regional importance, and in these Federal cooperation is desirable. Basic studies in soil dynamics are of national importance and the cooperation of Federal agencies to encourage such investigations is urgently needed.

The matter of administration in cooperative equipment research between State and Federal agencies is one which should be mutually understood in advance. The immediate leadership of a specific project should be under the most capable worker, whether he be a State or Federal representative. Administrative relationships in the research field can not be determined by rigid rules. The attainment of the end points of investigations in the most effective manner should be the guiding factor in working out relations between State and Federal agencies.

## RESEARCH PROGRESS IN 1927–28

The following outline has been prepared to indicate briefly the progress being made in mechanical farm equipment research during the year. This outline is indicative only of the types of problems being studied. In many instances but little progress is being made, owing to lack of personnel, funds, or equipment, or a combination of these conditions.

[* Indicates projects to be actively supported by the advisory council]

A. Soil dynamics and tillage
- *(*a*) Measurement of tilth.
  1. No definite progress. Several States interested.
- *(*b*) General soil dynamics.
  1. Alabama, Nebraska, and North Dakota have projects on, or directly related to, this subject.
  2. Nebraska, Alabama, Iowa, and California have projects involving tractor-lug efficiencies.

B. Weed control.
- (*a*) The Montana station is working with weed burners.
  California is developing some related data.
- (*b*) Ohio has conducted some work in connection with corn production.

C. Crop-production studies.
- *(*a*) Corn.
  1. The Illinois, Iowa, Ohio, Virginia, Pennsylvania, and Montana stations have studies under way.
  2. The United States Department of Agriculture and the stations in Michigan, Indiana, and Ohio have investigated corn production with reference to corn-borer control.
- *(*b*) Cotton.
  1. South Carolina, Texas, Alabama, Mississippi, and the United States Department of Agriculture have investigations under way involving equipment application.
  2. Georgia and Arkansas are considering studies.
- (*c*) Wheat.
  1. See report on combines.
- (*d*) Hay and forage.
  1. See grain and forage processing.
- (*e*) Tobacco.
  1. No reports.
- (*f*) Fruits.
  1. California has worked on fruit and nut dehydration.
  2. Washington and California have made some studies on apple and pear washing.
  3. See pest-control machinery.
- (*g*) Cane (sugar).
  1. Louisiana has a project on machinery for sugar-cane production.
- (*h*) Potatoes.
  1. Pennsylvania.

D. Harvesting studies.
- *(*a*) Combine methods.
  1. The following States have made studies of combine methods of harvesting in 1927: Idaho, Illinois, Indiana, Iowa, Kansas, Louisiana, Michigan, Minnesota, Montana, New York, North Dakota, Pennsylvania, South Dakota, Virginia, and Wisconsin.
  2. Illinois, Indiana, and Virginia investigated the use of combines for harvesting soy beans in addition to wheat and other small grains.
  3. New York and Indiana experimented with combining buckwheat.
  4. Minnesota experimented with combining flax.
  5. Minnesota and Indiana experimented with sweet clover.
  6. Louisiana used the combine for harvesting rice.
  7. Kansas made studies on combining grain sorghums.
  8. Iowa studies were confined principally to oats.
  9. Wheat was combined in practically every State.

  Other crops included in addition to those mentioned above were red clover, timothy, rye, barley, "succotash," and millet.
- *(*b*) Corn harvesting.
  1. The United States Department of Agriculture made studies in connection with corn-borer control.

D Harvesting studies—Continued.

*(*b*) Corn harvesting—Continued.

2. Kansas, Minnesota, Indiana, Illinois, Iowa, New Hampshire, New York, Virginia, Oregon, and Washington have conducted studies on silo filling in connection with rural electrification work.
3. Iowa is conducting studies on harvesting cornstalks for by-product utilization.

*(*c*) Cotton harvesting.

1. Texas and United States Department of Agriculture are studying mechanical cotton pickers.
2. The Oklahoma Engineering Experiment Station has a project on mechanical cotton pickers.

*(*d*) Hay harvesting.

1. See forage processing.
2. Montana and Pennsylvania have conducted some field experiments.

(*e, f, g, h*) Tobacco, fruits, cane, and potatoes.

1. No reports.

*E. Grain and forage processing.

(*a*) Grain drying.

1. Kansas, Wisconsin, Illinois, Indiana, Ohio, Pennsylvania, North Dakota, New York, Virginia, and United States Department of Agriculture have studies under way relating to grain drying.

(*b*) Forage drying.

1. Indiana, Texas, Louisiana, and New Jersey are working on problems relating to forage drying.

(*c*) Grain grinding.

1. Alabama, Idaho, Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Nebraska, New York, Ohio, Oregon, South Dakota, Virginia, Wisconsin, and Missouri are studying grain grinding in connection with the activities of the committee on relation of electricity to agriculture.

(*d*) Forage grinding.

1. Idaho, Indiana, Kansas, and South Dakota have made studies of forage grinding.

(*e*) Silage cutting.

1. See corn harvesting.

*F. Pest-control machinery.

(*a*) The United States Department of Agriculture is conducting extensive tests of machinery in connection with corn-borer control.

(*b*) Illinois, Indiana, Michigan, Wisconsin, and Ohio are working on corn-borer equipment.

(*c*) California, Washington, and Oregon have investigated stationary spraying plants.

(*d*) California has a project on the application of heat for pest control.

*G. Fertilizer studies.

(*a*) The United States Department of Agriculture has a project on fertilizer machinery.

(*b*) New Hampshire has studied fertilizer grinding and mixing.

(*c*) California has a project on fertilizer application.

*H. New machines. (Studies encouraged where necessary.)

(*a*) New machines being tested out include cotton pickers, stubble beaters, corn combines, soy-bean harvesters, shock and windrow gatherers, soil tillers, grain-sorghum harvesters, apple washers, walnut dehydrators, field burners, sweet-clover harvesters, forage driers, grain driers, etc.

*I Dairy equipment.

(*a*) Milkers.

1. Alabama, Illinois, Indiana, Iowa, Kansas, Missouri, New Hampshire, Ohio, Oregon, South Dakota, Virginia, and Wisconsin have carried on milking-machine studies.

(*b*) Sterilizers.

1. California, Oregon, Alabama, Illinois, Wisconsin, and Minnesota have experimented with sterilizers.

*I Dairy equipment—Continued.
- (c) Bottle washers.
  1. Kansas and New Hampshire have made investigations.
  2. California has a study on commercial types of can and bottle washing equipment.
- (d) Drinking cups.
  1. Minnesota.
- (e) Milk coolers.
  1. New Hampshire, New York, and Oregon.
  2. California has a project on efficiencies of spray and flood methods of milk cooling.
- (f) Grinders.
  1. See grain grinding.
- (g) Ventilators (mechanical).
  1. Minnesota.

*J. Water-supply equipment.
- (a) Houshold systems.
  1. Alabama, Colorado, Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, New Hampshire, New York, Ohio, Oregon, Virginia, Wisconsin, and South Dakota have made studies.
- (b) Irrigation.
  1. California, Kansas, Washington, Nebraska, Oregon, Virginia, and Alabama are studying irrigation pumping.
  2. Utah is studying drainage by means of pumps.
- (c) Water softeners.
  1. No report.

The above outline does not include many of the projects under investigation by experiment stations and the committee on the relation of electricity to agriculture, although the projects under headings E, I, and J are largely the result of studies in rural electrification. Other studies include farm refrigeration, fly control, incubation, brooding, wear of plowshares, grain-handling machinery and methods, grain-treating equipment, orchard heaters, straw-saving equipment, truck-farming machinery, farm-lighting plants, draft studies of implements, economic machinery surveys, and other investigations relating to mechanical farm equipment.

## COOPERATION OF THE EQUIPMENT INDUSTRY

The extensive use of equipment in agricultural production in the United States has resulted in the development of a great basic industry—the farm-implement industry. The value of the products of this industry in 1924 was $323,367,127; in 1925, $391,812,436; and in 1926, $461,399,528. On the basis of the foregoing figures it is not unlikely that the value of its products for 1927 exceeded $500,000,000. The production tendencies in the fewer but bigger factories that now characterize the industry are toward quality and volume. The success of such methods of production depends almost entirely upon the value of the products to the consumer. Accordingly, the implement industry is more interested than ever before in determining the exact functions of farm machines.

It has been pointed out that State and Federal research agencies should not do what industry can best do for itself; on the other hand, analytical methods of determining the functions of machines utilized by agriculture are not readily applied by a manufacturing industry. These require the assistance of agricultural specialists who appreciate the importance of the various farm-production functions performed by machines.

The experiment stations—which after all are the technical laboratories of the agricultural industry—are in a position to render service to these industries along the general restricted lines of investigation heretofore described. To most effectively render such services, however, requires a willingness upon the part of industry to cooperate with the State and Federal research agencies in the development of fundamental facts. These facts can not be developed for specific machines or products, but they should be determined with respect to types or classes of equipment which are of importance to agriculture. For each particular manufacturing industry to get the most from such State and Federal research requires that they, in turn, develop their own research departments in a way which will enable them to translate into terms of their own products the fundamental data developed. Moreover, the assistance of industry is not only helpful but is urgently needed by experiment stations in many research problems.

Frequently the products of industry may be needed to carry on research projects. The cooperation of the industry in these matters always has been most generous. Farm machines have been lent for numerous investigations, many of which have had no equipment objectives. Unless the study does have some direct equipment objectives, the loan of machines becomes merely a matter of generosity or good will upon the part of the industry. This last-mentioned practice is of doubtful value to industry because it resolves itself into an advertising feature rather than a contribution to agricultural research.

The loan of equipment for research having either direct or related equipment objectives should be encouraged, since this practice constitutes a valuable contribution to research. Industry, however, is justified in inquiring into the objectives of an investigation before loans are made. Less generosity and more active cooperation in the loan of farm equipment for research would have a beneficial influence in promoting studies of benefit to the implement industry as well as to agriculture. Those industries which build up research departments for the purposes herein outlined will undoubtedly derive the greatest benefit from equipment research conducted in our State experiment stations, and incidentally it is only through such methods that the full benefits of these investigations will finally acrue to agriculture.

It is not likely that State experiment stations, through the usual station projects, will be able to conduct all of the basic agricultural research of importance to the equipment industry. The study of special phases of important problems is frequently encouraged by research fellowships established in educational institutions and supported by the industries directly interested. This is a practice already followed by the steel, electrical, clay products, fertilizer, packing, and certain other industries, but as yet not recognized by the manufacturers of farm-operating equipment. This method of encouraging research for particular purposes deserves the attention of the equipment industry.

## FUNDS FOR FARM-EQUIPMENT RESEARCH

The States and the Federal Government have given rather liberal support to agricultural research, and the results so far obtained more than justify the expenditures made in this direction. The equipment of agriculture, however, has received but little attention. The early acts passed by Congress for the Federal support of original investigations made no direct reference to the problems of production and manufacture of agricultural products except to include a clause, following the mention of specific problems, as follows (*6, sec. 2; 7 sec. 1*): "* * * and such other researches or experiments bearing directly on the agricultural industry of the United States as may in each case be deemed advisable * * *." At the time of the passage of these acts the importance of machinery as a factor in production was not generally recognized.

The Purnell Act, passed in 1925, was much more specific, as the following excerpt indicates (*8, sec. 1*):

> The funds appropriated pursuant to this act shall be applied only to paying the necessary expenses of conducting investigations or making experiments bearing directly on the production, manufacture, preparation, use, distribution, and marketing of agricultural products and including such scientific researches as have for their purpose the establishment and maintenance of a permanent and efficient agricultural industry * * *.

The equipment of agriculture certainly is an important factor in the production and manufacture of its products and has a very definite relation to the establishment and maintenance of a permanent and efficient agricultural industry. There should be no difficulty in securing Purnell funds for equipment investigations if these will result in useful and practical information on subjects connected with agriculture.

The council through its director has made some inquiry regarding the funds now being used for agricultural-engineering research, including investigations in rural electrification and farm-operating equipment. Figures have been secured from 44 States. These show that in 1926–27, $275,711 was expended for agricultural-engineering research through the State experiment stations. Of this amount, $166,631 was used for farm-equipment and rural electrical investigations. Of this total, $80,297 was expended by 26 States reporting on farm-machinery research, while $86,334 was expended by 20 States reporting rural electrical studies. These latter studies have been subsidized largely by the electrical industry during the past few years. In 1926–27 more than $60,000 of the $86,334 spent for rural electrification in 20 States was furnished as cash from commercial sources. In this connection it is interesting to note the sources of support for the agricultural-engineering investigations as reported by 44 States, 10 of which report no work whatever. These are shown in Table 1.

TABLE 1.—*Sources of funds for agricultural engineering investigations in 34 States, fiscal year 1926–27*

| Source of fund | Amount |
|---|---|
| Agricultural experiment stations | $137,520 |
| Engineering experiment stations | 10,890 |
| Private funds (from commercial sources) | 69,891 |
| Institutional funds other than experiment stations funds or from private sources | 57,410 |
| Total | 275,711 |

If the funds from private sources be deducted from the total shown in Table 1, the balance is $205,820. Of this balance approximately 67 per cent comes from agricultural experiment station funds, approximately 5 per cent comes from engineering experiment stations, and 28 per cent from other institutional sources. On this basis, if the $69,891 in private funds be deducted from the $166,631 total used for farm-equipment research which includes rural electrification, the balance, or the support from public funds, is $96,740. On the percentage basis as above determined, $64,816 represents agricultural experiment station support, $27,087 represents institutional support, and $4,837 comes from engineering experiment stations. When one considers that more than $12,000,000 is spent annually for agricultural research, and that nearly $1,000,000 is spent annually by the engineering experiment stations [14] of our land-grant institutions, it would seem that the funds allotted for farm-equipment research are entirely out of keeping with the importance of the subject.

On the other hand, it must be recognized that this type of research is new and as yet not fully organized. The response of station directors to suggestions for research development in this field indicates increased support, and no doubt funds will be made available for projects which fit into the agricultural programs of the respective States. A number of stations have material increases in funds for use in 1927–28.

The use of institutional and private funds for equipment investigations indicates a recognized need for such work. It should be remembered, however, that the private support has been largely for special electrical studies, and that this support will decrease rather than increase in the future.

The United States Department of Agriculture, through the division of agricultural engineering, Bureau of Public Roads, gives direct support to various phases of agricultural engineering research. In 1927 this amounted to $184,600 distributed for research approximately as follows:

| | |
|---|---|
| Irrigation investigations | $78,806 |
| Drainage and land clearing | 55,670 |
| Buildings, sanitation, water supply | 18,811 |
| Farm-operating equipment | 31,313 |
| Rural electrification | 00 |
| | 184,600 |

Figures showing the distribution and sources of funds for agricultural-engineering research and the number and distribution of workers in the various fields are included in Appendix 7. These figures are not exact in every detail, but they do indicate in total the financial and personnel status of agricultural-engineering research in the United States in 1926–27. The State reports in irrigation and drainage are incomplete since in a number of State institutions, investigations in these fields are conducted by other workers, as for example, civil engineers and agronomists.

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[14] ASSOCIATION OF LAND-GRANT COLLEGES AND UNIVERSITIES, ENGINEERING SECTION. ENGINEERING RESEARCH AT LAND-GRANT COLLEGES AND UNIVERSITIES. Engin. Expt. Sta. Rec. (8) 1: 6. 1928. [Mimeographed.] 1926–27 funds $851,921; 1927–28 funds $1,085,565.

## THE PERSONNEL FOR EQUIPMENT RESEARCH

Carleton R. Ball says:[15] "The four chief factors concerned in every piece of research have been defined as (*a*) the problem, (*b*) the personnel, (*c*) the plan, and (*d*) the equipment." This report has been confined principally to the problems and the plan of attack of research in mechanical farm equipment. Of all these factors, however, personnel is undoubtedly the most important. Before any research program can be put into successful operation, it must be backed by capable personnel.

In farm-equipment research an engineering personnel that can work with agricultural scientists is necessary in analyzing the various problems. The responsibility for the development of the technical end points of such research falls directly upon the agricultural engineers. Needless to say, such workers must be trained engineers having an understanding of agricultural principles, and they should be in sympathy with the ultimate objectives of the agricultural industry. Moreover, they must be good cooperators.

Thirty-four States now conducting research in agricultural engineering have the equivalent of 65.4 full-time workers. However, the actual number of workers engaged in some phase of agricultural engineering research is much larger, since many are devoting but a small percentage of their time to investigational work. Table 2 indicates the total number of part-time research workers in the respective agricultural engineering fields, the approximate average percentage of time devoted to research activities, and the equivalent of full-time research workers. These figures are taken from the reports of 34 States. Ten other States reported no research activities in this field.

TABLE 2.—*Distribution of agricultural engineering workers in 34 States, 1926–27*

| Type of study | Number of part time workers | Per cent of time devoted to research | Number of equivalent full-time workers |
|---|---|---|---|
| Rural electrification | 52 | 34.88 | 18.14 |
| Farm operating equipment | 64 | 32.75 | 20.96 |
| Buildings, sanitation, and water supply | 43 | 21.82 | 9.38 |
| Drainage and land clearing | 29 | 25.48 | 7.39 |
| Irrigation | 23 | 41.43 | 9.53 |
| Total | [1] 211 | | 65.40 |

[1] Includes duplications.

It is shown by Table 2 that about the same number of workers are giving attention to farm-production equipment as to rural electrification. This situation has been due largely to the private support given to the latter studies by the electrical industry.

[15] BALL, C. R. SOME ELEMENTS OF SUCCESSFUL COOPERATION IN RESEARCH. 42 p. Washington, D. C. 1925. (U. S. Dept. Agr., Bur. Plant Indus.) [Mimeographed.] (Address before the special conference of directors of State agricultural experiment stations, Apr. 20, 1925, St. Louis, Mo.)

The percentage of time given to research by those conducting investigations in farm-operating equipment is relatively small. This gives rise to the question of how much time should a worker have before he actually undertakes research work. It is evident that full-time men will do more effective work than an equivalent number of workers devoting only part time.

The lack of stability in the staffs of agricultural engineering departments is a handicap to well-organized research. The fact that agricultural engineering is growing in importance and that the opportunities in this field are increasing rapidly has a tendency to cause a shifting of workers within institutions and also from institutions into industry. This condition is likely to continue for some time.

Station directors responsible for the expenditure of public funds for research are justly reluctant to approve research projects in farm equipment unless they have rather definite assurance that workers are available to complete projects in a creditable manner. The lack of an adequate number of qualified research workers in this field is one of the most serious handicaps in establishing and expanding a comprehensive research program in mechanical farm equipment. This situation, however, should not hinder some expansion at the present time, since the personnel facilities in many of the institutions will permit of considerable immediate expansion. Eventually, however, the rate of expanson is more likely to be governed by personnel rather than by equipment or funds.

The personnel of the division of agricultural engineering, Bureau of Public Roads, is an important factor in the development of agricultural-engineering research. The research personnel of this division is estimated at 39 full-time men. The distribution of research workers in the division of agricultural engineering for the various phases of agricultural-engineering research is as follows:

| | |
|---|---|
| Irrigation investigations | 17.0 |
| Drainage and land clearing | 12.5 |
| Buildings, sanitation, and water supply | 3.5 |
| Farm operating equipment | 6.0 |
| Rural electrification | 0 |
| Total | 39.0 |

## FARM-EQUIPMENT RESEARCH FACILITIES

The research facilities at the different State experiment stations vary considerably. In general, these are in keeping with the size of the respective staffs. The problem of physical equipment is less difficult than that of personnel, although the need of technical apparatus is more or less urgent at every institution. Housing facilities are generally crowded and inadequate. A number of institutions have only one agricultural engineer, and it is apparent that such institutions will require additional station workers before research of an extensive nature can be attempted. In general, the problem of equipment to conduct research—aside from that of technical apparatus—is not a serious one and should not be an obstacle to research development.

## APPENDIX 1. GENERAL OUTLINE FOR A PROJECT ON THE MEASUREMENT OF SOIL TILTH

Name.

The measurement of soil tilth.

Introductory statement.

Tillage operations require more energy input than does any other agricultural operation. The preparation of soils to develop tilth is important and expensive. It is a major farm operation, and a wide range of tools and machines has been devised for various tillage purposes. While it is generally accepted that good tilth is essential for satisfactory crop production, no method of expressing or measuring tilth in a concrete manner has been devised which will convey a definite objective for such farming operations. At present the term "tilth" is a loosely used expression having a value as variable as the judgment of the different individuals who use it.

The purpose of many agronomic practices in farming is to produce a soil condition which will contribute to optimum tilth for the particular crop produced. This requires energy input and machine processes in an amount for each crop as may be determined by the judgment of the farm operator.

Efficient tillage should involve a minimum of energy input, whether in the form of labor or of machine methods, to produce a soil condition favorable for optimum tilth. To determine just what this condition should be is a question of great economic importance to those engaged in crop production, and to those responsible for the design and manufacture of machines utilized for tillage purposes. A practical method of measuring tilth which will express the objectives of tillage operations is desirable in the development of an economic and efficient agriculture.

Definition of tilth.

For the purposes of this project, tilth is understood to mean that physical condition of the soil which, when considered with climatic environment, is most favorable for plant growth. It is recognized, however, that this condition can not be constant for all plants and may vary for different soil types as well as for different periods of the life history of the plant.

Objects.

To determine what physical effects soil tillage machinery must accomplish in order to produce optimum condition for seed-bed preparation and subsequent plant growth.

To determine and measure the immediate and subsequent effects of these tillage operations on the physical conditions of the soil.

To correlate these determinations and measurements with plant growth, for the purpose of devising methods and expressions for the measurement of soil tilth which may be utilized for definite objectives in tillage, machine design, and field tillage operations.

Method of procedure.

1. *General.*—Since the primary object of tillage is to produce conditions favorable for plant growth, the ultimate test of tilth must be found in its effect upon the plant itself. Accordingly, in making a study of methods for the measurement of tilth, the plant should be the final check.

In plots or field experiments, therefore, standard approved agronomic practice should be adhered to, methods of correction of results by numerous check plots being used. For the preliminary work, and as a guide to further procedure, the opinions of agronomists must be obtained and used as empirical standards regarding (1) the desired state of soil fineness and structure, and (2) the plant requirements as to soil aeration, temperature, moisture, etc., as indices to tilth.

2. *Weathering effects.*—Sufficient evidence is available to lead to the tentative hypothesis that tilth is not produced directly by tillage machinery, but that tillage implements merely process the soil into a state that natural agencies may have a greater effect. These agencies are, for example, wetting and drying, freezing and thawing, rapid heating and cooling, and the action of small organisms. If this premise is correct, the object of tillage would be to place the soil in the best condition to be affected by these agencies. For this reason, measurements of climatic changes by the standard methods of the United States Weather Bureau should be a part of the investigations.

3. *Experimental plots.*—Plots for field investigations should be of sufficient size to permit the operation of standard field machinery. Every fifth plot should be used as a check plot, and the check system of interpreting crop yields should be followed. It is important that the area selected have a uniform character and that all plots have a uniform history regarding tillage and fertilization. The details for the organization of the plot procedure should follow approved agronomic practice. It is suggested that the check plots be given such treatment as will produce what the agronomist terms "a good state of soil tilth." Other plots will be plowed various depths and given various machine treatments before and after plowing.

4. *Plot series.*—The treatment should in general include the following:

Series 1. Plots with little organic matter:

- (*a*) Plots with little or no treatment except to destroy weeds and cover the seed.
- (*b*) Plots treated by machinery to produce a finely pulverized soil.
- (*c*) Plots plowed so as to bury weed seed.
- (*d*) Plots plowed but weed seed indifferently covered.
- (*e*) Plots plowed and compacted.
- (*f*) Plots plowed and loosely worked.
- (*g*) Plots plowed to varying depths.
- (*h*) Plots plowed and worked at varying moisture ranges.

Series 2. Plots with large amounts of organic matter:

- (*a*) Plots with little or no treatment except to destroy weeds and cover the seed.
- (*b*) Plots treated by machinery to produce a finely pulverized soil.
- (*c*) Plots plowed so as to bury weed seed.
- (*d*) Plots plowed but weed seed indifferently covered.
- (*e*) Plots plowed and compacted.
- (*f*) Plots plowed and loosely worked.
- (*g*) Plots plowed to varying depths.
- (*h*) Plots plowed and worked at varying moisture ranges.

5. *Measurement of tilth.*—Arbitrary indices of tilth will be devised and the correlation of these indices with plant growth will be made to determine their value. The following are suggestive only, and others should be tried.

(*a*) Penetrometer measurements: It is assumed that a soil in good tilth, in general, will offer less resistance to the penetration of a sharp instrument than the same soil in a poor condition of tilth. Instruments for performing this will be devised and soil tests and measurements taken at determined intervals.

(b) Apparent specific gravity: Since apparent specific gravity is an index of soil structure, it should also be tried as an index of tilth.

(*c*) Crumbling modulus: Since tilth is apparently correlated with resistance to crumbling, a certain volume of dried soil will be taken with a specific-gravity tube and mechanically shaken in a sieve having a mesh twice the size of the largest-sized particle classified as sand, and the time noted for the soil (except gravel) to pass through. From these data a crumbling modulus should be devised.

6. *Measurement of related factors to tilth.*—In addition to the determination of a measure of tilth, other factors of importance affecting tillage will be measured and correlated with plant growth. The most important of these are the following:

- (*a*) Temperature changes in the soil and the soil atmosphere gradient.
- (*b*) Moisture conditions.
- (*c*) Air movements in the soil.
- (*d*) Weed conditions.
- (*e*) Plant food available. (In cooperation with agronomists.)
- (*f*) Condition of crust formations.
- (*g*) Bacterial checks. (In cooperation with bacteriologists.)

7. *General cooperation.*—It is suggested that one or two stations adopt a comprehensive program based on the general plan as herein outlined, and that other States having varying soil and climatic conditions, cooperate on similar plots to determine the significance of developed methods under a wide range of conditions.

8. *Cooperative relations.*—

## APPENDIX 2. GENERAL OUTLINE FOR A COOPERATIVE PROJECT IN FARM MACHINERY FOR THE SOUTHERN STATES

### Name.

A study of the fundamental factors involved in machine methods of production of cotton and other principal crops of the Southern States.

### Introductory statement.

Cotton is the principal cash crop of the Southern and Southeastern States. It is produced under a wide range of conditions of topography, climate, soil fertility, and output per worker. The total cotton production during the past few years has been increasing, owing to favorable crop conditions and to expansion of acreage, particularly in the Great Plains areas of Oklahoma and Texas. This has resulted in lower unit prices for the product, with a resulting loss of income, if not of entire profits, to producers. The economic depression caused by this condition has been most keenly felt in the older cotton regions where the acreage of cotton per worker is smallest and where the farm-labor market must compete with the labor market of a rapidly growing industrial section.

The area of cotton produced per farm worker varies greatly, from as low as 5 acres in some of the older regions to more than 200 acres in the Great Plains section. In spite of the greater production per acre and better quality of product in the older sections, the large producers of the western cotton section are more prosperous because of their low labor cost in production, brought about by the extensive use of farm machinery.

In the production of this basic farm crop under the usual small-scale methods, approximately two-thirds of the costs consist of power, labor, and machinery. It is evident that the greatest hopes of the individual farmers lie in getting more cotton per unit of labor and other expenses. This implies greater individual efficiency not only through increased quality and quantity of production per acre, but also through more acres of production per worker.

The introduction of machine methods in the cotton-growing areas where hand-labor methods have been extensively followed for many years involves numerous farm-machinery problems not only as to use, adaptability, and economic farm practices, but also as to the development of many basic requirements of farm machines to meet the needs of the cotton farmer in carrying out an economical and efficient farm program, and to provide for the implement industry basic facts regarding requirements and principles upon which efficient and economical farm machines may be designed.

The project statement which follows has been prepared through the cooperation of the advisory council of research in mechanical farm equipment, United States Department of Agriculture; the farm machinery committee of the southeast section of the American Society of Agricultural Engineers; and the research committee of the American Society of Agricultural Engineers.

### Objects.

To determine the fundamental requirements which crop production equipment must meet for machine methods of production of cotton and other principal crops of the Southeastern and Southern States as a basis for the design of such equipment and its economic utilization, taking into account the physiological and ecological requirements of crops in their relationship to the physical effect which the machine must produce on and in the soil, or on the plant itself, for the development of optimum conditions for crop production.

To determine and study the limitations produced by physical controlling factors such as topography, etc., with the object of securing basic information required for the design of farm machines and the adaptation of existing machines.

To obtain practical data on methods of utilization in order to overcome, so far as possible, the effect of these deterrents to machine methods of production.

### Method of procedure.

1. *General.*—The project as herein outlined represents a composite program for cooperative investigations between such States of the South and Southeast as may be mutually interested. The scope and extent of the objectives are so broad that it is hardly probable that a single State will desire to undertake the entire program. The attainment of the objectives, however, is essential for a satisfactory solution of the project, and it is hoped that the several

States cooperating will select from the project as many phases of the general program for thorough study as the personnel and funds of the respective stations will permit. While it is intended that each institution shall follow its own judgment in the selection and study of problems, it is hoped there will be a sufficient diversity of interest to insure a concerted study of the entire project.

The farm machinery research committee of the southeast division of the American Society of Agricultural Engineers, which is composed of representatives from the interested States, is suggested as the coordinating body for the conduct of cooperative studies.

While no financial obligation between the several States is possible or intended, it is expected that the States joining in the investigations will cooperate and advise each other as to different phases of the project selected for study, and as to the general method of attack, and will submit to the cooperating stations copies of all reports of progress which may be regularly required by the directors of the respective stations.

The procedure which follows is suggestive of the development of the various phases of the project.

2. *Preliminary field studies.*—To obtain a clear view of the machine problems in their practical aspects and to select the more important factors for study in the respective territories, preliminary field studies of the following general nature should be made to determine:

(*a*) The kind, character, and extent of farm equipment, power units, and labor units now utilized in crop production so that man hours, horse and mule hours, and power hours for the various field operations may be properly allocated.

(*b*) The condition and methods of utilization of existing farm equipment and power with respect to size of farm, character of crops, etc.

(*c*) The factors limiting the use of larger farm machines, such as size of farm, topography, soil fertility, drainage methods, and field obstacles, and the extent of such limitations in each respective territory.

(*d*) The relationship of farming types to machinery needs, with special reference to machines influencing labor peaks and offering promise of utilization in the production of rotation and off-peak crops.

(*e*) The location of actual farms for practical field experiments where such are desirable in attaining the objectives of the project.

3. *Development of specific research problems.*—A thorough analysis of the field studies will be required to develop suitable and logical problems for research in the respective stations, after which methods must be devised for detailed investigations that will point toward definite objectives.

4. *General method of attack.*—In general, existing agronomic requirements and practices will be recognized except in cases where they involve a large labor input which offers promise of being diminished by machine methods of production. In such specific cases the cooperation of the agronomist will be sought.

The mechanical and physical principles of machine design will be tested to determine how these meet the physiological and ecological requirements of specific crops of the respective areas, utilizing at the outset, so far as possible, the improved machines now on the market. Where such machines fail to meet the requirements of the field practice, new machine principles must be evolved and tried out in specially designed equipment.

In general the method of attack will be by analysis; that is, by sorting out or separating the limiting or controlling factors in the application of machines to crop production. These controlling factors should in themselves direct attention to logical methods of procedure. Naturally, in a majority of instances, at the outset of the study the simple substitution of a machine method to decrease hand labor will appear as a control factor; yet, as the investigations proceed, these controls will shift to the more technical aspects involving the mechanical principles of machine design in relation to the effect the machine should produce upon the soil and the plant itself.

While it is contemplated in this program that well-established and generally accepted field methods should be acknowledged as good practice for the starting point in these investigations, the objective is to develop machines and methods which meet the basic requirements of a crop in its soil and climatic environment for each particular region. Existing methods in many localities often represent a wide divergence in practice, involving wide variations in machine capacities and requirements and consequently a wide divergence of labor input. It is important, therefore, that the basic requirements of the plant itself be determined and met, with an objective of minimum of energy input, and that all practices and customs of production be subjected to critical analysis as a basis of machine design as well as for the establishment of field practices.

For example, considerable time and energy are expended in working flat, broken land into cotton beds to meet a recognized practice in cotton production; now if a method just as good and requiring less energy input can be developed, then the process of bedding could be profitably eliminated. Similarly, the practice of seeding large amounts of cotton seed for the purpose of insuring the ability of the young cotton plants to break through possible surface crusts—with subsequent chopping out of excessive plants—might be modified as a result of studying the conditions of crust formation as produced by planting and tilling implements, by using improved planting methods, by using treated seeds, or by a combination of these methods. Similarly with other crops, the ultimate economic practice can be obtained only by systematic experimentation, taking into account cause and effect and thus distinguishing between actual requirements and accepted field practice.

The detailed procedure for particular States must be varied to meet the character of the projects contemplated. It is intended that laboratory work permitting exact methods of measuring controlled variables will be followed in studying basic requirements, to supplement observations and measurements in experimental plots, and that plot studies will in turn, be supplemented by more extensive experiments and practical application to be conducted on experimental fields, or with selected farm cooperators. It is probable that, due to the varying conditions of soil and topography, two or more States may undertake simultaneous studies of certain phases of the general program.

5. *Suggested problems.*—The problems which follow are suggestive only and are stated in terms of their practical or economic aspect, leaving the technical procedure and detailed research methods entirely to the cooperating agencies.

(a) Field studies to determine the possibilities or extent of the application of machine methods of production of cotton and other major crops.

(b) The development of cotton-planting equipment and methods for:

(1) Full-hill dropping to overcome chopping and other labor requirements.

(2) Use of lint and delinted seed for economical planting.

(*a*) Methods of delinting seed.

(*b*) Effect of use of delinted seed on planting rates and labor requirements such as chopping.

(*c*) Effect of delinting of seed on germination.

(*d*) Effect of delinting of seed on growth resistance—that is, ability to grow through soil crusts.

(*e*) Advantages and disadvantages of scarifying delinted cottonseed.

(*f*) Effect of early germination of seed on weed and pest control.

(3) Determination of the value of check-rowing cotton.

(c) Investigations of various types of tillage devices to determine:

(1) Methods of improving labor efficiency in production.

(2) Adaptability of various types of machines to increase productive efficiency.

(3) Adaptability of various types of tillage machines for use with crops in rotation. or off-peak production.

(4) Experiments with different types of tillage machines to determine:

(*a*) If the principles of design may be changed to increase efficiency.

(*b*) If changes can be made in tillage practices which will contribute to more efficient production.

(*d*) An investigation of improved methods of harvesting to increase labor efficiency and maintain quality of production by:

(1) Combination of hand and machine methods.

(2) Full machine methods.

(*e*) Investigation of ginning operations.

(1) Relation of harvesting methods to ginning problems.

(2) Effect of ginning methods on quality of lint.

(*f*) Effect of machine methods of production on the organization of the farm.

(*g*) An economic analysis of the use of improved farm machines with the objective of determining the net return per farm worker.

6. *Cooperative relations.*—

## APPENDIX 3. RESEARCH IN MECHANICAL FARM EQUIPMENT—STATUS OF PROJECTS AND PROBLEMS

The following is an anlysis of the status of the projects and problems prepared by H. B. Walker from the Report of a Survey of Research in Mechanical Farm Equipment by J. B. Davidson.[16]

Nine States are conducting 11 projects having a bearing on the general subject of farm machinery. Eighteen problems were submitted.

Fifteen States report 26 projects having a direct economic bearing on mechanical farm equipment. Twenty or more problems of this general nature were submitted, and practically all problems submitted have an economic bearing in this general field.

A few States only are working on design problems. Eleven suggested problems were submitted.

Six States are conducting eight different projects relating to draft tests. Five problems were submitted.

One State has a lubrication project. Six problems were submitted.

Six States and the United States Department of Agriculture are conducting three projects relating to some phase of corn or sorghum production. Twenty problems were submitted.

Five States and the United States Department of Agriculture have eight projects relating to cotton production. Eighteen problems were submitted.

Seven States have nine projects relating to soil dynamics and tillage. Fourteen direct problems were submitted and many others have a direct relationship if logically studied.

Seven States have 10 projects relating in some way to plows and ridging devices. Twenty-six problems were submitted, many of which relate to soil dynamics and machine design. Other tillage machines have not been analyzed in detail.

The United States Department of Agriculture and 11 States are studying some phase of combine harvesters. Fifteen problems were submitted, many of which are included in projects under way.

Nine States are carrying on some phase of hay harvesting work covering six problems. Nine problems were submitted.

Twenty States have 32 projects covering some phase of grain and forage processing, due largely to investigations of the committee on the relation of electricity to agriculture.

Four States are conducting work on some phase of dehydration. Six problems were submitted.

The United States Department of Agriculture and four States are conducting fertilizer studies relating to methods and machinery. Eight problems were submitted.

Six States have seven projects on spraying and orchard equipment. Seven problems were submitted.

Two States and the United States Department of Agriculture have projects relating to mechanical equipment for the control of pests. Six problems were submitted.

Eight States have projects covering some phase of grain handling equipment carried on largely through the committee on the relation of electricity to agriculture. Three problems were submitted.

Sixteen States have 23 projects relating to dairy equipment, conducted largely through studies of the committee on the relation of electricity to agriculture. Fourteen problems were submitted.

Six States are doing work in farm-power economics in addition to that carried on by the committee on the relation of electricity to agriculture. Three general problems were suggested.

Four States have six studies relating to animal power. Six problems were submitted.

Sixteen States report 32 projects relating to the use of electric power in agriculture, mostly conducted through the committee on the relation of electricity to agriculture activities. Twenty-three problems were submitted.

Fourteen States have 22 projects relating to tractors. Thirty problems were submitted.

A study of the proposed problems indicates that the solution of the certain classes depends upon finding an answer to a few basic problems common to a

[16] DAVIDSON, J. B. Op. cit.

large number. For example, many of the problems in tillage—such as those relating to new machines, and machine efficiencies—depend upon the development of some method of measuring tilth. Only one State (California) is directly concerned with the measurement of tilth, although two others (Alabama and Nebraska) are considering this problem. Eleven of the fourteen suggested problems in soil dynamics depend upon tilth; 8 out of 26 problems in plows are dependent upon tilth; and 44 of the 94 problems suggested on tillage machinery can not be satisfactorily solved unless a basis for tilth measurement can be found. Many of the problems relating to tractor-wheel equipment could be included also in this classification.

Forty-eight of the suggested problems relate to new machines.

Forty-four of the suggested studies relate to problems most of which must be met by the engineering departments of manufacturing concerns with more or less cooperation from experiment stations.

Twenty-four problems, mostly relating to standardization, can be best handled by societies and associations as, for example, "an investigation of wagon standardization."

## APPENDIX 4. TECHNICAL SOCIETY AND TRADE ASSOCIATION PROBLEMS

A list of problems for technical societies and trade associations to study, as classified by H. B. Walker, from the suggested research problems submitted in the Report of a Survey of Research in Mechanical Farm Equipment, by J. B. Davidson.[17]

.3. Machinery and equipment.
- .301. History.
  1. Preparation of a history of the development of agricultural machinery and its relation to agricultural progress.
  2. Biographical history of the men who have contributed to the development and improvement of farm equipment.
- .3041. Cost of farm machinery.
  1. A study of the cost of producing and distributing farm machinery.
- .305. Design.
  1. The preparation of a standard nomenclature for names of farm-machine parts and operating terms.
  2. A study to determine if the factors of safety in farm machines conform to good engineering practice.
- .307. Lubrication.
  1. The preparation of specifications for motor oil.
- .3111. Plows and tillage machines.
  1. Standardization of plow shares.
- .3121. Grain seeders and drills.
  1. Reduction in the weight of grain drills.
- .3135. Haying machinery.
  1. Standardization of the cutting parts of mowers.
- .321. Feed mixers, grinders, and cookers.
  1. The development of a standard method of grading gound feed with a satisfactory designation for each grade.
- .333. Vehicles.
  1. Investigations of wagon standardization.
- .339. Miscellaneous.
  1. The development of standard methods for the rating of farm machines.
  2. An investigation of the possibility of standardization of, or the elimination of unnecessary sizes of, farm machinery.
  3. The development of standard codes for the testing of farm machinery.
  4. A study of safety devices for farm machinery and the prevention of accidents.
- .340. Power.
  1. A historical review of the influence of power upon agricultural production.

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[17] DAVIDSON, J. B. Op. cit.

.3. Machinery and equipment—Continued.

.404. Power transmission.

1. A study for more complete standardization of belt speeds and pulley sizes.

.445. Electric power.

1. How may rural electric systems be best financed?
2. A study of the proper regulation of rural electric systems.
3. An investigation of an equitable system of rural electric rates.
4. A determination of the correct relationship between the manufacturer and the purchaser of an isolated electric plant.
5. The development of standard specifications for the construction of rural lines.

.461. Tractors.

1. Standardization of tractor hitches.

## APPENDIX 5. RESEARCH IN MECHANICAL FARM EQUIPMENT

### NEW MACHINES

A list of suggested new machines prepared by H. B. Walker from the research problems submitted in the Report of a Survey of Research in Mechanical Farm Equipment, by J. B. Davidson.[18]

.3 Machinery and equipment.

.3111. Plows and tilling machines.

1. Development of a plow for the Texas black lands.
2. Development of a stump and rock plow.
3. Development of a tiller machine.
4. Development of a ridge leveler for irrigated orchards.
5. Development of 1-way disk harrows.
6. Development of machines for furrowing out and cultivating beneath grapevines.
7. Development of mechanical cotton choppers.
8. Development of a cane-trash chopper.
9. Development of a machine for reducing cornstalks.

.312. Seeding machines.

1. Development of a combination fertilizer and seeding machine for regional requirements.
2. Development of a machine for seeding grass seed at a uniform depth and rate.
3. Development of multiple-row corn planters.
4. Development of a machine for planting sugar cane.
5. Development of more accurate potato planters.
6. Development of larger seeding units for beets, peas, corn, and potatoes.

.313. Harvesting machines.

1. Development of machines for harvesting grain sorghums.
2. Development of machines for harvesting sweet clover.
3. Development of corn pickers.
4. Development of a 2-row corn snapper.
5. Development of a special corn harvester for flint corn.
6. Development of a practical corn-harvesting machine.
7. Development of machinery for cotton harvesting.
8. Development of a machine that will lift, top, and load sugar beets.
9. Development of potato diggers, graders, and conveying machinery.
10. A study and development of shock loaders.
11. Development of a small clover huller.
12. Development of a continuous hay baler to work on windrows.
13. Development of cotton-ginning machinery for a harvester crop.
14. Development of a cotton-delinting machine.

.3149. Crop-processing machines.

1. A machine to sort and pack asparagus.
2. A machine to wash, bunch, and tie vegetables.

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[18] DAVIDSON, J. B. Op. cit.

.3. Machinery and equipment—Continued.
  .3149. Crop-processing machines—Continued.
    3. A machine to pit peaches and apricots.
    4. A machine to clean sand from raisins in field.
    5. A machine to efficiently hull almonds.
  .315. Dusting, spraying, etc.
    1. Machines for European corn borer control.
  .316. Fertilizer machinery.
    1. Practicability of a plow and fertilizer distributor.
    2. Development of equipment for chopping and shredding baled fertilizer materials.
    3. Development of equipment to spread and chop bean straw after a combine.
    4. Development of equipment to load and pulverize manure.
  .321. Feed mixers, grinders, and cookers.
    1. Vacuum cleaners for dairy-barn work.
    2. Development of a mechanical gutter cleaner for dairy barn.
  .33. Vehicles.
    1. Trailers for tractors.
  .36. Construction machinery.
    1. Development of machinery to keep open ditches cleaned.
  .366. Land clearing.
    1. A machine to saw off stumps even with ground.
  .461. Tractors.
    1. The development of special tractor equipment to be attached directly to and operated by tractor.
    2. Development of a hillside tractor.

## APPENDIX 6. MANUFACTURERS' PROBLEMS

A list of manufacturers' problems as classified by H. B. Walker from the suggested research problems submitted in the Report of a Survey of Research in Mechanical Farm Equipment by J. B. Davidson.[19]

.3. Machinery and equipment.
  .305. Design.
    1. Do conditions call for better and higher-priced machines?
    2. A study of the wearing parts of farm machines to secure longer life and better service.
    3. A study of an economical method of preventing rust on bright metal surfaces.
    4. A study of the practicability of using nonrusting metals in farm machines.
    5. A study of the use and efficiency of antifriction bearings in farm machines.
    6. A study of the factors affecting rolling and other resistances in farm machines.
    7. A study of the efficiency of various methods of lubricating farm machines.
    8. A study of the requirements of an oil filter.
    9. A study of the use of stainless steels in plows.
    10. A study of the use of alloy steels in farm implements.
    11. A study of the practicability of lightweight heat-treated steel in farm machinery.
    12. Development of easily replaceable cutting edges for plowshares.
    13. A study of better weight distribution in disk harrows.
    14. A study of the correct curvature of disk blades.
    15. The development of cultivator shields.
    16. The development of cultivator mechanisms to be operated by power take-off from tractor.
    17. The development of cultivating mechanisms for garden tractors.
    18. A study of the weight and design of grain drills.
    19. The development of multiple-row farm machines.
    20. A study of weight distribution in mowers.

[19] Davidson, J. B. Op. cit.

.3. Machinery and equipment—Continued.

.305. Design—Continued.

21. The development of speed-control devices for tractor-driven mowers.
22. Development of spraying equipment operated by a tractor power take-off.
23. A study of bolts and pulleys suitable for farm machines.
24. A study of the various phases of power transmission in farm machines.
25. The development of power take-off drives from tractors.
26. The development of special hardware for making hitches and eveners.
27. Further development of the general-purpose tractor.
28. The development of special tractor equipment to be directly attached to and operated by the tractor.
29. Cold-weather starting devices for tractors.
30. Improved lubrication systems for tractors.
31. Improved tractor lugs.
32. Investigation of tractor speeds.
33. A study of the possibilities of steam or vapor cooling for the tractor motor.
34. Investigate the possibilities of the sealed tractor motor.
35. Study the possibilities of the tractor truck.

## APPENDIX 7.—DISTRIBUTION OF FUNDS AND PERSONNEL FOR AGRICULTURAL ENGINEERING RESEARCH IN THE UNITED STATES FOR THE YEAR JULY 1, 1926, TO JUNE 30, 1927

| State | Source of funds | | | | | Men employed | Equivalent full-time men | Division of funds | |
|---|---|---|---|---|---|---|---|---|---|
| | Agricultural experiment station | Engineering experiment station | Institutional | Private | Total | | | Salaries | Project maintenance |
| Alabama | $5,950 | | | $3,800 | $9,750 | 6 | 3.28 | $4,750 | $5,000 |
| Arizona | 7,950 | | | | 7,950 | 4 | 2.50 | 6,950 | 1,000 |
| Arkansas | 1,500 | | $2,405 | 500 | 4,405 | 4 | 1.37 | 3,330 | 1,075 |
| California | 18,980 | | | 7,000 | 25,980 | 7 | 4.25 | 14,180 | 11,800 |
| Colorado | 6,500 | $5,000 | 6,500 | | 18,000 | 4 | 4.00 | | [1] 18,000 |
| Florida | 940 | | | | 940 | 2 | .60 | 940 | |
| Georgia | | | 2,675 | 800 | [2] 3,475 | 3 | .40 | 1,275 | 2,200 |
| Idaho | 2,700 | | 825 | 1,310 | [3] 4,835 | 3 | 1.05 | 2,325 | 2,510 |
| Illinois | 3,250 | | 5,861 | 4,126 | 13,237 | 7 | 3.20 | 7,877 | 5,360 |
| Indiana | [4] 8,200 | | | 7,500 | 15,700 | 4 | 3.17 | 9,380 | 6,320 |
| Iowa | 10,680 | 3,500 | | 4,500 | 18,680 | 7 | 3.93 | 12,840 | 5,840 |
| Kansas | | 1,090 | 4,962 | 4,400 | 10,452 | 6 | 3.00 | 7,462 | 2,990 |
| Louisiana | 5,484 | | | | 5,484 | 2 | 1.05 | 3,050 | 2,434 |
| Massachusetts | 1,075 | | | | 1,075 | 1 | .25 | 975 | 100 |
| Michigan | 7,980 | 500 | | | 8,480 | 5 | 2.10 | 5,590 | 2,890 |
| Minnesota | | | 18,767 | 5,100 | 23,867 | 18 | 6.77 | 15,400 | 8,467 |
| Mississippi | 150 | | 400 | | 550 | 1 | .15 | 400 | 150 |
| Missouri | 2,300 | | | 4,000 | 6,300 | 4 | 1.79 | 2,776 | 3,524 |
| Montana | 6,695 | | [5] 1,100 | | 7,795 | 3 | 1.07 | 2,805 | 4,990 |
| Nebraska | 8,110 | | 3,715 | 1,145 | [6] 12,970 | 6 | 2.70 | 8,200 | 4,770 |
| New Hampsbire | | | | 8,000 | [7] 8,000 | 1 | 1.00 | | 8,000 |
| New Mexico | 6,400 | | | | 6,400 | 2 | 1.08 | 3,500 | 2,900 |
| New York | 2,400 | | 6,590 | 810 | 9,800 | 8 | 2.20 | 6,380 | 3,420 |
| North Dakota | 2,818 | | | | 2,818 | 1 | .50 | 1,500 | 1,318 |
| Oklahoma | [8, 9] 200 | | 240 | | 440 | 1 | .10 | 240 | 200 |
| Oregon | | | | 6,000 | 6,000 | 2 | 1.70 | 4,280 | 1,720 |
| Pennsylvania | 5,800 | | | | 5,800 | 2 | 1.15 | 4,500 | 1,300 |
| South Carolina | 300 | | | 600 | 900 | 1 | .25 | 300 | 600 |
| South Dakota | 3,733 | | | | 3,733 | 2 | .88 | | [7] 3,733 |
| Tennessee | 1,900 | | | | 1,900 | 1 | .50 | 900 | 1,000 |

[1] Includes salary and Federal cooperation.
[2] $2,500 additional in 1928.
[3] Over $9,000 in 1928.
[4] Includes $3,500 for corn borer.
[5] Income from projects.
[6] $4,000 additional in 1928.
[7] Includes salaries.
[8] $16,375 for 1927–28.
[9] $600 additional for 1928.

Appendix 7.—*Distribution of funds and personnel for agricultural engineering research, etc.*—Continued

| State | Source of funds | | | | | Men employed | Equivalent full-time men | Division of funds | |
|---|---|---|---|---|---|---|---|---|---|
| | Agricultural experiment station | Engineering experiment station | Institutional | Private | Total | | | Salaries | Project maintenance |
| Texas | | | $2,410 | $5,800 | $8,210 | 7 | 2.24 | $6,035 | $2,175 |
| Utah | $6,225 | | | | 6,225 | 3 | 1.50 | 4,625 | 1,600 |
| Virginia | 2,600 | [10] $800 | 960 | 1,800 | 6,160 | 5 | 1.57 | 4,060 | 2,100 |
| West Virginia | 700 | | | | 700 | 1 | .25 | 650 | 50 |
| Wisconsin | 6,000 | | | 2,700 | 8,700 | 8 | 2.85 | 8,700 | |
| Total | 137,520 | 10,890 | 57,410 | 69,891 | 275,711 | 142 | 64.40 | 156,175 | 119,536 |
| Division of agricultural engineering, Bureau of Public Roads | | | | | [11]184,600 | | 39.00 | 138,450 | 46,150 |
| Grand total | | | | | 460,311 | | | 294,625 | 165,686 |

[10] Special equipment.
[11] Includes pro rata of general administrative, drafting, stenographic, and clerical expense and of the cost of supplies, equipment, and miscellaneous items.

## DIVISION OF WORK BY TYPE OF INVESTIGATION

| State | Rural electrification | | | Farm operating equipment | | | Buildings, water supply, etc. | | | Drainage, terracing, etc. | | | Irrigation | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Men employed [1] | Equivalent full time | Funds | Men employed [1] | Equivalent full time | Funds | Men employed [1] | Equivalent full time | Funds | Men employed [1] | Equivalent full time | Funds | Men employed [1] | Equivalent full time | Funds |
| Arizona | 1 | 0.50 | $3,800 | 4 | 2.45 | $5,950 | 1 | 0.33 | | | | | | | |
| Alabama | 2 | .10 | 390 | 1 | .05 | 95 | 2 | .30 | $1,000 | 1 | 0.05 | $135 | 4 | 2.00 | $6,330 |
| Arkansas | | | | 3 | .52 | 1,360 | 3 | .85 | 3,045 | | | | | | |
| California | 1 | .90 | 10,200 | 4 | 2.30 | 12,000 | 2 | 1.00 | 3,500 | 1 | .05 | 280 | | | |
| Colorado | | | | | | | 1 | 1.00 | | | | | 4 | 4.00 | |
| Florida | | | | 2 | .50 | 590 | | | | 1 | .05 | 175 | 1 | .05 | 175 |
| Georgia | | | | 2 | .15 | 555 | 3 | .20 | 2,670 | 1 | .05 | 250 | | | |
| Idaho | 2 | .35 | 2,135 | | | | | | | | | | 2 | .70 | 2,700 |
| Illinois | 3 | 1.15 | 2,831 | 5 | 1.30 | 3,200 | 3 | .68 | 1,674 | 2 | .07 | 283 | | | |
| Indiana | 2 | 1.02 | 7,500 | 3 | 1.90 | 7,175 | | | | 1 | .25 | 1,025 | | | |
| Iowa | 3 | 1.30 | 6,300 | 3 | 1.22 | 5,520 | 3 | 1.16 | 4,860 | 1 | .25 | 1,500 | | | |
| Kansas | 4 | 1.50 | 5,970 | 5 | 1.00 | 2,517 | 4 | .50 | 1,965 | | | | | | |
| Louisiana | | | | 1 | 1.00 | 5,334 | | | | 1 | .05 | 150 | | | |
| Massachusetts | | | | 1 | .25 | 1,075 | | | | | | | | | |
| Michigan | 3 | .80 | 3,250 | 2 | .60 | 1,825 | 1 | .50 | 2,265 | 1 | .20 | 1,140 | | | |
| Minnesota | 7 | 1.69 | 6,590 | 2 | .12 | 766 | 6 | .55 | 1,553 | 9 | 4.41 | 14,849 | | | |
| Mississippi | | | | 1 | .15 | 550 | | | | | | | | | |
| Missouri | 3 | 1.07 | 4,000 | 3 | .35 | 472 | 1 | .10 | 500 | 2 | .27 | 320 | | | |
| Montana | | | | | | | 2 | .16 | 450 | 2 | .71 | 1,730 | 2 | .20 | 625 |
| Nebraska | 1 | .45 | 2,945 | 4 | 1.90 | 8,045 | 3 | .30 | 1,770 | | | | 1 | .05 | 210 |
| New Hampshire | 1 | 1.00 | 8,000 | | | | | | | | | | | | |
| New York | 4 | .60 | 1,785 | 4 | 1.15 | 6,075 | 4 | .45 | 1,940 | | | 200 | 3 | 1.08 | 6,200 |
| North Dakota | | | | 1 | .30 | 2,068 | 1 | .20 | 600 | | | | | | |
| Oklahoma | | | | 1 | .10 | 440 | | | | | | | | | |
| Oregon | 2 | 1.55 | 5,180 | | | | | | | | | | 2 | .15 | 400 |
| Pennsylvania | | | | 2 | 1.15 | 5,800 | | | | | | | | | |
| South Carolina | 1 | .10 | 120 | 1 | .15 | 780 | | | | | | | | | |
| South Dakota | 2 | .88 | 3,683 | | | | | | 50 | | | | | | |
| Tennessee | | | | 1 | .50 | 1,900 | | | | | | | | | |
| Texas | 5 | 1.46 | 6,175 | 4 | .70 | 1,715 | | | | 1 | .08 | 320 | | | |
| Utah | | | | | | | | | | 1 | .25 | 875 | 3 | 1.25 | 5,350 |
| Virginia | 3 | .72 | 2,480 | 3 | .80 | 3,290 | | | | | | | 1 | .05 | 390 |
| West Virginia | | | | | | | 1 | .25 | 700 | | | | | | |
| Wisconsin | 2 | 1.00 | 3,000 | 1 | .35 | 1,200 | 2 | .85 | 2,200 | 4 | .65 | 2,300 | | | |
| Total | 52 | 18.14 | 86,334 | 64 | 20.96 | 80,297 | 43 | 9.38 | 30,742 | 29 | 7.39 | 25,532 | 23 | 9.53 | 22,380 |
| Division of agricultural engineering, Bureau of Public Roads | 0 | 0 | 0 | | 6.0 | 31,313 | | 3.5 | 18,811 | | 12.50 | 55,670 | | 17.0 | 78,806 |

[1] Columns showing men employed contain duplications, since the same man frequently is engaged on two or more projects.

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## ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

**December 4, 1928**

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