U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF PLANT INDUSTRY—BULLETIN NO. 170.
B. T. GALLOWAY, *Chief of Bureau*

TRACTION PLOWING.

BY

L. W. ELLIS,
ASSISTANT, OFFICE OF FARM MANAGEMENT.

ISSUED MARCH 12, 1910.

WASHINGTON:
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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., November 24, 1909.

Sir: I have the honor to transmit herewith a report dealing with the present status of plowing with traction engines as the motive power, by Mr. L. W. Ellis, Assistant in the Office of Farm Management of this Bureau. The economy and practicability of the use of tractors for heavy farm work rather than the mechanical features involved are discussed in this paper. I recommend that this manuscript be published as Bulletin No. 170 of the special series of this Bureau.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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TRACTION PLOWING.

INTRODUCTION.

For several decades, or practically ever since the development of steam traction engines for thrashing purposes, attempts have been made to use these engines instead of horses for the heavier field work, especially plowing. In the beginning failure was the result in nearly every case. The engines available were of small size, such as were only sufficiently powerful to drive a grain separator and haul it from place to place. The plows used were in the main those designed for use with animal power and were unsuitable as to both weight and construction for use with engines. When enough plows of this sort were hitched together to utilize the power such an engine was capable of developing, the outfit proved to be unwieldy, especially in turning. The transmission through light, narrow traction gearing, designed for light loads, of power sufficient for pulling this number of plows usually resulted in expensive breakage. Accidents to plows were frequent, not only because of their unsuitability, but owing to the difficulty of stopping for obstructions before damage was done. The small capacity of the makeshift outfits and the inexperience of operators were additional handicaps, and little progress was made during a long period.

Following the growth of grain farming in the West, the demand for larger and faster thrashing outfits resulted in an increase in size until engines rated at 25-horsepower came into common use. These being very powerful were supposed by many farmers to be adapted for plowing, and since they were used only a short period each year for thrashing many were fitted with plows, with little more success than in previous attempts.

Early in the last decade the field for plowing engines attracted the attention of various manufacturers, who began to remodel and design their tractors with this end in view. In addition to strengthening the gears, axles, shafting, etc., on general-purpose engines, certain companies brought out special plowing tractors, usually of greater horsepower than could be economically used except for this one operation. With the introduction of this equipment, together with plows suitable for engine plowing, the practice had a rapid extension, and instances of successful operation became more numerous as equipment was improved and skilled operators were developed.

The opening up of vast tracts of level territory where the acreage to be broken was so great as to discourage the idea of turning it with single teams and horse plows created a lively demand for steam plowing outfits, and in this field more than any other have they demonstrated their practicability. Under favorable conditions the advantages are numerous. Large areas, which otherwise would have remained uncultivated, have been brought quickly into productiveness and have been cropped with a minimum of horse and man labor, which has constantly become more expensive. Crop returns have often been greatly increased through taking advantage of favorable soil and climatic conditions for getting the land in shape for seeding, especially in sections where these conditions are of short duration. Work at such times has been rushed, often continuing day and night. At other times, as in hot, dry weather, traction outfits have been used where horses could stand the work but a short period, if at all. Through concentration of power it has been possible to plow very difficult soils and to plow deeply, when desired, in ordinary soils.

Under favorable conditions the cost of traction plowing has been brought below that of horse plowing. Considering the total cost of prime mover, shelter, and incidental equipment, and the surplus of horses needed to keep a given number in the field, the investment in motive power is frequently reduced by the substitution of engines for horses in plowing, and maintenance during periods of idleness is greatly simplified. These factors and the possibility of obtaining greater service from thrashing engines have firmly established the practice of steam plowing in sections which by reason of topography, fuel and water convenience, and state of settlement are adapted to it.

The desire for economical motors in smaller units, together with the scarcity and high price of labor and the limited supply of coal and water in some localities, has created a demand for internal-combustion tractors which has kept in advance of their development. The first gasoline traction engine to be used successfully was put on the market about 1903. Since that time numerous other companies have entered this field with greater or less success, and many of the steam-engine manufacturers are now developing internal-combustion engines as well. The gasoline tractors are being used in the same localities and for the same work as the steam engines, and a few are being built in sizes approximately as large. They have been built also in small and medium sized units and are being introduced rapidly into sections to which large steam engines were not adapted.

GEOGRAPHICAL DISTRIBUTION OF TRACTION-PLOWING OUTFITS.

Traction plowing has reached its greatest development in the newer agricultural regions where land is level and held in large tracts. The accompanying map (fig. 1) shows the location of the operators of direct traction outfits who answered in detail a circular letter bearing on this subject sent out by the Office of Farm Management. In a general way, their number and distribution are representative of the whole number, though some sections are not properly represented, and it is estimated that the number shown is not more than $2\frac{1}{2}$ per cent of the total operating in 1908. A considerable number of outfits

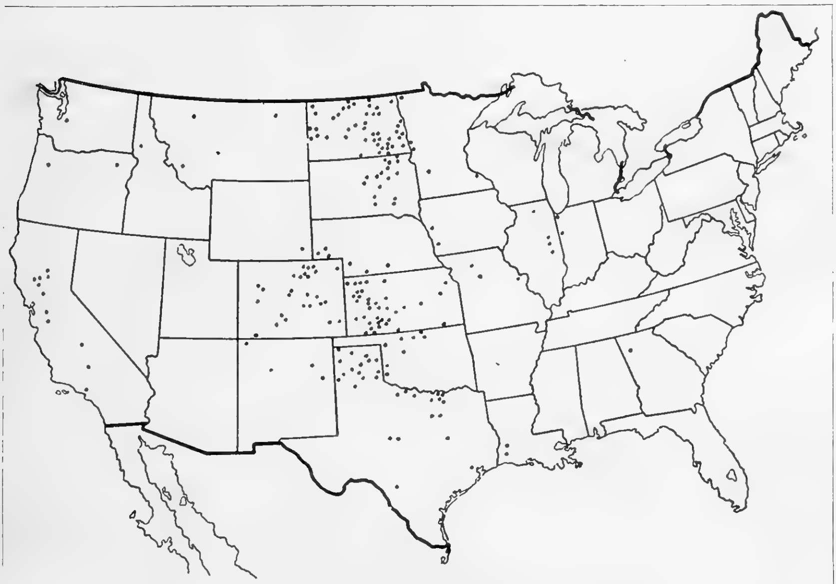

FIG. 1.—Map of the United States, showing the approximate location of the majority of the operators of traction engines who contributed the data contained in the tables presented in this bulletin. The total number of outfits on which data were secured is over 500, located in the United States and Canada. Many operators furnished only partial information.

are to be found in the valleys in Utah, Wyoming, Montana, and Idaho; also in certain favorable sections of New Mexico and of various Middle and Southern States, while much larger numbers than are indicated are to be found on the Pacific coast. East of the Missouri River and the Dakotas the outfits are well scattered. The conditions in the Canadian provinces of Manitoba, Alberta, and Saskatchewan resemble those in the Northwestern States, and a large number of outfits are found there. Some of the information derived from Canadian operators is included in the tables presented later in this bulletin.

PRINCIPAL TRACTION-PLOWING SECTIONS.

As will be noted from the map, three fairly distinct sections are to be found where traction plowing is common, namely, the Pacific Coast States; the Northwestern States, including North Dakota, South Dakota, and Minnesota; and the Southwestern States, including Kansas, Colorado, Oklahoma, and Texas. Within each section conditions are similar, but between the different sections considerable variation in practice is to be attributed to differences in natural conditions.

In the Northwestern States and in Canada much prairie sod remains to be broken and the land is held in large open tracts. Grades seldom are objectionable and the natural difficulties are chiefly wet weather, soft ground, hidden rocks, and pot holes or buffalo wallows. In some sections brush or scrub is a handicap. A low quality of coal is found underlying parts of this region and is occasionally used for fuel. The coal shipped in is of the usual quality, but becomes very expensive in some places. Straw, either loose or baled, is used for fuel to a large extent during the fall, though not so convenient as coal or wood. By plowing stubble land in the autumn dry footing is obtained, and the frost tends to loosen up any soil which may have been packed by the weight of the engine. Sod land is commonly plowed rather shallow in the spring and frequently backset in the fall. Moldboard plows are used almost exclusively both for "breaking" and on old land, as disk plows leave the sod in such shape that it disintegrates slowly. "Breaking" in this connection refers to the turning of wild sod. The farms in the Dakotas and Minnesota on which steam and the larger gasoline outfits are reported average 825 acres in size, 510 acres being in harvested crops.

Traction plowing is more common in the western part of Kansas and Nebraska than in the eastern part, where corn-belt conditions are found. Throughout parts of these States and in Colorado, New Mexico, Oklahoma, and Texas level land and large tracts make plowing outfits desirable. The lack of rainfall throughout a large portion of the year makes the ground dry and hard, and horse plowing at such times is practically impossible. In wet weather the advantage is reversed, but the season for traction-plowing outfits is of such duration as to enable a large acreage to be turned. Disk plows will penetrate the dry ground better than moldboard plows and permit of a longer plowing season; hence, they are used by the great majority of operators. In Colorado the moldboard plows are used quite largely for breaking alfalfa sod. In sage-brush prairie in this State breaking is unusually difficult, being reflected in reduced acreage and a higher plowing rate. Outfits reported from the Southwest are distributed about equally among farms under a half section, from a half section to a section, from one to two sections, and over two sections, 10 per cent being over four sections.

Semiarid conditions in both the southwestern and the northwestern regions foster the demand for a gasoline engine of large capacity, both on account of the labor problem and of the difficulty of obtaining either quantity or quality of water.

In California conditions are essentially different from those east of the mountains. Grain ranches are on a larger scale and employ larger units of equipment. Custom plowing is a minor item, the larger ranches furnishing work to the entire capacity of one or more outfits. The steam plow is a natural adjunct of the steam combined harvester and is frequently used with the latter to handle the crops, with the assistance of only such teams as are needed to haul supplies. The ground is in the best state for seeding for a short time only, and during this period every possible advantage is taken of the capacity of the big steam outfits. California-built plows of light draft but capable of covering large areas are popular, and the isolation of the State with respect to eastern manufacturers has contributed to the adoption of equipment designed and built by local concerns.

The South and the corn belt are not adapted to plowing with the large steam outfits now in use on account of the small fields, the lack of custom work, and the low price per acre to be had for custom plowing. A large part of the plowing in these sections must necessarily be done in the winter and spring after the late crops are harvested, and the heavy engines are not adapted for work on old land where much moisture is present. Moreover, there is little inducement for farmers in these sections to invest in a large plowing equipment where horses must be maintained without practical reduction in numbers for cultivating the crop. The development of gasoline tractors of comparatively low weight, price, and horsepower, which can be used in the fields to supplement the work of horses and elsewhere for a variety of purposes, seems likely to prove economical not only from the standpoint of investment and cost of operation and maintenance, but from that of increased returns through the application at times when it is urgently needed of power not ordinarily available.

Throughout the Eastern States small fields and heavy grades generally prove prohibitive to the use of even the smaller motors.

EQUIPMENT FOR TRACTION PLOWING.

The equipment for traction plowing varies according to location, natural conditions, and preference. The standard types may be considered under three heads: (1) Plows, (2) prime mover or engine, and (3) miscellaneous equipment, including all conveniences for the transportation of supplies, the repair of equipment, and the care and comfort of the crew. Harrows, rollers, and other tillage implements, which are frequently drawn in connection with the plows, may also be considered under the last head.

PLOWS USED WITH ENGINES.

Practically all traction plowing is now done with specially designed engine gang plows. These may be divided into the disk and moldboard types, and the latter into steam-lift and hand-lift. Engine gangs present greater variation in type and adaptability than do engines, and this is an important factor in such success as the practice of traction plowing has had. Variations in plow shapes, such as have been worked out for local conditions, apply as well to engine as to horse plows; hence the problem has been principally to combine plow units into large gangs in the most satisfactory manner.

DISK PLOWS.

Disk plows are popular with traction plowmen, as it is possible with them to cover more ground with a given expenditure of time and power than with moldboard plows. Furthermore, it is possible with them to plow a continuous furrow around a field without labor and loss of time in lifting plows at corners or headlands, though in this case the corners are usually left to be plowed out with horses. Disk plows, especially the smaller gangs, accommodate themselves readily to uneven surfaces and tend to roll over obstructions. They can be used under certain conditions where moldboard plows can not; yet it is doubtful whether, on the whole, they do as good work. They are usually hitched to the engine by means of cables or chains, and the matter of hitching has given rise to serious problems. It was found difficult to turn corners with all plows in the ground when small gangs were used; hence, the number of disks per gang was increased until ten, twelve, and even sixteen were hung on a single frame. Besides being extremely heavy to lift, the large gangs proved to be unwieldy and hard to keep in line. The resistance of all the disks was thrown upon the rear wheel, tending to crowd the gang to the left and making it necessary to weight the rear of the gang heavily to keep the plows in the ground. Balancing the hitch by placing it near the front of the gang transferred the difficulty to the guiding of the engine, since the center of the draft was not in the center of the drawbar. Gradually the five, six, and seven disk gangs, which have proved more successful than either extreme, were evolved.

Ordinary disks are 24 inches in diameter, though larger sizes are frequently bought, especially in sandy regions, where wear is rapid. From ten to fifteen disks is a medium load for the majority of gasoline engines, and from fifteen to twenty-eight for steam engines, varying, of course, with the horsepower of the engines, the condition of the soil, the width of the cut per disk, the depth, and whether or not harrows follow the plows. These plows cost from $125 to $175 for a medium-sized gang east of the Rocky Mountains and somewhat more on the Pacific coast, where the cost of a disk-plow equipment would range in most cases from $250 to $600.

MOLDBOARD PLOWS.

Moldboard engine gangs were developed in response to the demand for a more compact arrangement than was possible with horse plows, and large gangs followed naturally. Since these had to be raised and lowered frequently, gangs of three to six bottoms prevailed until the advent of steam-lift plows. These in reality consist of several gangs of four to six plows hung on a single frame, each gang being lifted and dropped by means of a cylinder supplied with steam from the engine. Plows of this type usually contain eight, ten, or twelve 14-inch bottoms, though larger sizes are built for special soils. Compactness and the possibility of backing and turning in close quarters have made the steam-lift plow popular, though the first cost is greater, ranging from $900 to $1,500 for ordinary-sized gangs.

Types of hand-lift plows embodying the size and compactness of the steam-lift plow consist of a frame to the rear of which the bottoms are attached. In both this and the steam-lift types flexibility is secured by making the bottoms vertically independent of each other or by combining them in pairs. Irregularities in ground surface are thus met and in case of a solid obstruction one or two bottoms may be released without damage to the whole outfit. In this type of hand-lift plow each bottom or pair of bottoms is raised and lowered by a lever, from six to fourteen being mounted on the frame.

The cost of these plows is considerably less than that of the steam-lift type, ranging from $500 to $900, but as a rule the latter can be operated with one man less to the outfit.

The smaller moldboard engine gangs usually contain from three to seven plows, the 14-inch bottom being practically universal. The frame is much heavier than in the case of horse plows and the cost per bottom greater, ranging, within reasonable distance from the factory, from $100 for three furrows to from $200 to $250 for six. In some types, especially in small gangs, the plow bottoms are held rigidly, but in the larger gangs the tendency is to give each plow a certain freedom, as in the case of the steam-lift type. At present six to eight bottoms for gasoline and twelve to fourteen for steam engines are maximum sustained loads for most conditions.

A cheap and fairly effective modification of the moldboard plow known as the Stockton gang is used widely on large ranches in California. This consists of a triangular frame holding on a rigid standard from three to eight reversible plow shapes cutting 8 to 10 inches each. It is adapted to shallow plowing, stirring rather than turning the soil, and with the large engines used in that section a great acreage can be covered in a day, a strip 30 to 40 feet wide being not uncommon.

ENGINES.

The prime movers used for plowing are mainly of two types: (1) The ordinary steam traction engine and (2) the internal-combustion engine using a liquid fuel, such as gasoline, kerosene, or distillate, and commonly spoken of as a gasoline engine. Since the conditions surrounding their operation are essentially different, these two types will be taken up separately and discussed in connection with the results obtained from the use of each.

Steam engines are much more common than gasoline engines as factors in traction plowing. The variations in mechanical detail are numerous, though as a class these engines are more nearly standard than the gasoline tractors. The principal variations are in type of boiler, cylinder arrangement, and mounting. The horizontal boiler is found in the majority of engines, with either direct or return flue arrangement. In the former, which is most common, the products of combustion pass directly from the fire box through the flues to the front of the boiler and the smokestack. In the latter the gases pass to the front of the boiler through a large flue, returning through smaller tubes to a stack at the rear of the boiler.

All ordinary arrangements of cylinders are to be found on leading plowing engines. These include single and double cylinders, not compounded, and compound engines, in which steam is admitted first to a small cylinder and partially expanded and then to a larger cylinder where advantage is taken of its further expansion, both cylinders thus working through a shorter range of temperature. The arrangement of compound cylinders gives rise to the terms "tandem" and "cross-compound," signifying cylinders placed one ahead of the other and side by side, respectively. Some cross-compound engines may be converted at will into double simple engines, thus gaining additional power, as for starting a load, at a sacrifice of economy.

In most cases the driving mechanism is mounted on the boiler, though occasionally built upon a frame entirely separate. Where these parts are beneath the boiler they are said to be "under-mounted." The same term is used to describe a tractor in which the main axle extends under the boiler, ahead of the fire box. Frequently the traction wheels revolve on bracket axles bolted to the sides of the fire box. This is termed "side mounting." A very satisfactory axle position is in the rear mounting, in which continuous axles are fastened to the rear of the boiler. The ideal arrangement for a plowing engine is a driving mechanism supported entirely without strain on either boiler or fire box, yet fully protected from the clouds of dust which arise in plowing.

All plowing engines are equipped with wide drive wheels to prevent miring in soft ground and loss of power through slippage. The traction gearing is wider than on thrashing engines, and is usually of steel or semisteel. Bunkers for several hours' coal supply and tanks for from one to three hours' water supply are provided, though in plowing it is usually necessary to take supplies about once an hour.

To withstand the strain and secure tractive efficiency these engines are of great weight, ranging from 7 to 20 tons. In the largest engines some reduction in weight and gain in strength are effected by substituting steel for cast iron. Throughout the entire construction emphasis is placed upon resistance to the tremendous strain of a heavy dead load on the drawbar.

Steam engines used for plowing are usually rated at from 20 to 50 tractive horsepower, most of them being between 25 and 35 horsepower. This is an arbitrary rating, placed near the efficiency of the engines as compared with horses, and much below the actual horsepower as measured by a brake test. The latter measures the power available for driving stationary machinery. It must be remembered that the power of a horse is measured in effective pull, while the engine will do many more foot-pounds of work per unit of time while standing still than when moving. Much of the power developed is used in moving the tractor and some is lost in transmission, while a reserve must be maintained for such emergencies as the horse can overcome by exerting for a short time as high as four or five times his normal efficiency. It is true that under like conditions a certain increase in power may be had of a steam engine, but to discourage overloading on the start and accidents in case of sudden obstacles the rating is usually placed at from one-fourth to one-third the brake horsepower. No general rule is followed. Both tractive and brake ratings should be known in connection with a general-purpose engine and should be placed at the point of maximum durable load rather than at the absolute maximum which can be sustained for a short period.

The cost of these engines varies with the locality and terms of purchase. Net factory prices quoted by manufacturers in the Middle West range from $1,500 to $3,000 for the sizes just mentioned. On the Pacific coast the common type of engine is larger, rating at 60 tractive and 110 brake horsepower, and selling, fully equipped, at from $5,000 to $6,000, according to terms and equipment.

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MISCELLANEOUS EQUIPMENT.

In addition to engines and plows, miscellaneous equipment requiring the expenditure of a considerable sum is necessary in operating a steam outfit. There must usually be at least one coal wagon of the ordinary farm type, costing probably $75, and a second, called the "trap" wagon, for carrying repair parts, tools, and odds and ends. The tank wagon, with either a steel or wooden tank holding 10 to 16 barrels, is usually purchased with the engine, its price being included. Purchased separately it will cost from $75 to $200. A drag harrow, disk harrow, roller, crusher, or planker is usually a part of the outfit. Blacksmithing and miscellaneous tools cost from $20 to $50. In a few cases, where water is near the surface, permanent wells are sunk at convenient intervals and a small gasoline engine used for pumping. Quite often the custom operator carries an engine and attaches it to the farmer's well rather than depend on wind power. For plowing at a distance from headquarters, either a tent or cook shack, the latter on wheels, is advisable, as with this equipment the crew loses no time in going to meals during the day or to the engine in firing up in the morning. The shack, complete, will cost from $200 to $300 as a rule, and occasionally $500. Teams will add to the investment, but are for convenience included as a part of the labor cost of operating. As an average first cost of miscellaneous equipment for steam-plowing outfits $500 is estimated.

FACTORS AFFECTING THE ECONOMY OF OPERATION OF STEAM OUTFITS.

The factors entering into the economy of either steam or gasoline plowing include not only those concerning the operation of equipment, but those arising from the effect of the practice upon the management of the individual farm and upon the agriculture of a section. The latter have been outlined somewhat in the introductory paragraphs, but owing to the nature of the problem this investigation has been confined chiefly to study of the cost of operation, the factors governing which are more clearly defined. The essential factors are so many and so varied that certain ones may easily be overlooked; hence, they will be discussed in some detail.

COST OF OPERATION.

The actual cost of operation includes not only the cash outlay for labor, fuel, oil, repairs, etc., but the interest and depreciation on equipment. The figures presented in this connection are not to be taken as final, because (1) very few operators keep accurate accounts, (2) depreciation and repair charges must be based almost entirely on estimates, only a small proportion of plowing outfits having actually been worn out, and (3) with the improvement in equipment and with the education of operators the efficiency of outfits must be gradually increased. Detailed estimates of the cost of plowing are given by sections.

OVERHEAD CHARGES.

Among the factors in the cost of plowing which are very often disregarded by operators who have not had a business training are the overhead charges, which include interest on the money invested and the depreciation of the outfit. If the outfit is bought on time the matter of interest is necessarily brought to the owner's attention. However, it is a frequent practice among owners who have paid cash to allow nothing for interest on their capital, thus apparently increasing the net profits from their work when as a matter of fact the venture may not be paying as good a rate of interest as might have been obtained by depositing the capital in an ordinary savings bank. Seven or 8 per cent interest is a common rate on machinery notes in the sections where traction plowing is most common.

The matter of depreciation is probably even less considered by the average operator than that of interest. Depreciation charges should be made in order that at the expiration of the life of the outfit a sufficient amount shall have been set aside either to replace the outfit in its original condition or to restore to the owner his original capital. The rate of depreciation depends, of course, upon the wear and tear on an outfit during a given period of use, or, in other words, upon the life of the outfit. The practice of traction plowing is so new that the average life of plowing engines can not be accurately determined, and the rapid improvements in equipment make of little value such figures as are obtainable from outfits already partially worn out. The life of plowing engines depends not only on the care given and the amount of work done, but upon natural conditions, such as climate, soil, topography, and in the case of steam engines the water used in the boilers. The soil in particular, with respect to its resistance, uniformity, and grittiness, exerts a great influence on the life and repairs of both engines and plows.

Manufacturers of steam outfits vary in their estimates of the life of plowing engines from four and one-half years when given maximum use to twenty years for ordinary use with excellent care. The general opinion of the manufacturers ranges between eight and twelve years, converging at ten. The factor of use per year must be taken into consideration. In California eleven owners of large steam engines plowing nearly 3,500 acres per year each make an average estimate of fifteen years. Thirty out of seventy-six correspondents in the Southwest estimate ten years as the life of their engines, the average of the whole number being 10.04 years. The average acreage per year reported from these operators is 1,075. In the Northwest and Canada thirty-two out of eighty-five operators estimate 10 years, and the average estimate is 10.7 years. Their average acreage per year is 797. Taking the two sections together and considering, as before, only those operators who state the annual acreage and the estimated life, sixty-two out of one hundred and sixty-one agree on ten years, the average being 10.4 years, while the average area plowed per year is 903 acres.

The consensus of opinion regarding the life of engines used in plowing and thrashing might fairly be taken as a basis for estimating the rate of depreciation, but closer inquiry in the field reveals the fact that while many engines of the type now being put out will have a life of ten years the majority of operators do not expect ten years' service in plowing. A great many place the plowing service at from four to six years, after which, when equipped with new gears and generally rebuilt, the engines are fit for service in thrashing as long as the boiler lasts, which may easily reach a like period thereafter. For this reason it is probable that the majority of correspondents who placed the life of their plowing engines at ten or more years misunderstood the question asked in the circular letter sent out by the Office of Farm Management. After duly considering all the data and estimates regarding the life of plowing engines, a rate of 10 per cent of the first cost of the engine is taken as the value consumed annually *in plowing alone* during the first five years of the life of the outfit.

Since approximately 90 per cent of the engines reported as plowing are used also for other purposes—principally thrashing—and an average of reports indicates approximately equal periods of plowing and thrashing, a division of the interest and depreciation charges on the basis of comparative wear and tear becomes necessary. The wear and strain on engines in the two operations is essentially different, being heaviest on different parts during each. When thrashing, the wear is mainly on the engine parts, and in plowing on both the engine parts and the traction gearing. The wear in plowing has been variously estimated at from two to ten times that in thrashing. The opinion of several of the leading manufacturers and other authorities centers about 75 per cent of the total wear as chargeable to plowing, as compared to 25 per cent for thrashing during equal periods of service. Since the reports from operators indicate practically the same number of days' plowing and thrashing each year, these figures are taken as the basis for dividing the overhead charges. Repairs might be included under this head, since they can be divided on this basis, but it has been considered more appropriate to include them under running expenses.

Following the method outlined of calculating and dividing the overhead charges, the division on an engine costing $3,000 would be, for the first five years, at the rate of 10 per cent depreciation and $5\frac{1}{4}$ per cent interest for plowing, $3\frac{1}{3}$ per cent depreciation and $1\frac{3}{4}$ per cent interest for thrashing. With regard to the calculation of interest, however, the average investment during each five-year period must be ascertained. Granting the approximate correctness of the preceding assumption, it is seen that the total rate of depreciation of the engine will be $400 a year and at the end of the fifth season the value will have been reduced to $1,000. As interest is taken on the value of the engine at the beginning of each season, the average value during the five seasons is seen to be $2,200. Interest at 7 per cent, therefore, would be $154 each year, or $115.50 for plowing and $38.50 for thrashing. Depreciation during the same time would be $300 and $100, respectively. During the last five years of the life of the engine both interest and depreciation would be chargeable to thrashing, the former at the rate of 7 per cent on an average valuation of $600 and the latter at an average rate of $200. As a matter of fact, the establishment of depreciation charges must be largely theoretical even in the most carefully conducted manufacturing or transportation enterprises, but the matter is one which should be carefully figured upon by every operator. Few traction engines are ever actually worn out; hence, the values are seldom reduced to a practical zero. Without extended investigation, which it is hoped may be undertaken, accurate figures covering the entire life of traction engines are not to be had, but without such figures from a considerable number of operators the estimates given are as likely to indicate the truth as any which might be made.

With regard to the life of plows and minor equipment, no data are at hand and depreciation is charged arbitrarily at 10 per cent. Plow depreciation is of course wholly chargeable to plowing, but that of miscellaneous equipment, being due to practically equal use in plowing and thrashing, is charged equally to both.

REPAIRS, OIL, ETC.

As previously stated, the division of repairs may be made on the same basis as that of overhead charges. From such data as are at hand, together with estimates from men in a position to have considerable knowledge on this point, it is possible to arrive in two ways at the cost of repairs per acre plowed. The average cost of repairs per year is estimated by several authorities at $100, of which $75 would be chargeable to plowing. Other authorities estimate the cost of engine repairs per acre at from 6 to 10 cents, and data from those operators who reported on this point indicate the latter figure as close to the average. It may be, however, that their figures covered the cost of repairs chargeable to thrashing and that an estimate of 10 cents per acre for engine repairs would probably cover the cost of keeping the majority of engines in good condition for work. Plow repairs are estimated at from 75 cents to $2 for each working day, including the expense of sharpening. The latter is much greater in the case of moldboard plows than with disk plows; hence, in estimating the cost of plowing, a larger figure per acre is allowed in the Northwest than in the Southwest.

In addition to expenses for repairs, labor, fuel, etc., from 2 to 5 cents per acre must be allowed for various lubricants, including crude oil for traction gearings, engine and cylinder oil, grease, and hard oil.

LABOR.

From three to six men are needed in operating a steam-plowing outfit. One guides, and a second usually fires the engine. One of these frequently looks after the plows. A third man and team supply the engine with water and fuel, and two men with teams are needed if supplies are to be hauled any great distance. Frequently one man gives his entire time to the plows, while a cook is needed in many cases. The engineer is naturally the best paid, receiving, according to correspondents, an average of $3.12 per day in the southwest group of States, $4.43 in the northwest group, and $4.30 in California. The guider's wage is more uniform, averaging $1.88. The plowman and teamsters are paid from $1.50 to $1.75 in most cases, the former having a slight advantage, while $1 is the common figure for the cook. In many cases it would be economy to pay much higher wages for the engineer, at least, as good management and efficient help tend to reduce delays through accidents or other causes. Board at 50 cents a day for each man and 75 cents for the use and board of each horse are usually to be added to wages in arriving at the labor cost. The majority of operators furnish board, many boarding but not paying the men on idle days. In estimating the labor cost per acre in this bulletin no account has been taken of wages, board, and keep of teams on idle days, but this amount, if it could be ascertained, should be added to the total. It is doubtful whether, on the average, steam-plowing outfits are able to work more than two days out of three during the plowing season, owing to accidents, moving, bad weather, and other causes.

The average daily cost of fuel, as gathered from operators, is given elsewhere under estimates of the cost of plowing. The quantity and cost per acre vary with the locality, the kind and cost of fuel, the acreage plowed per day, the condition of the soil, the construction of the engine, the efficiency of the operator, and perhaps other factors.

Coal is most used in steam tractors, though wood is used to a limited extent, and straw in some sections. Crude oil is used extensively in California.

WATER.

In steam plowing the quality and proximity of water are important factors. As the daily consumption ranges from 1,500 to 5,000 gallons, the labor involved is considerable, and is much increased with the hauling distance. Muddy or alkali water by depositing a sediment in the boiler reduces the evaporation per pound of coal consumed, necessitates frequent washing of the boiler, and causes rapid depreciation of the flues. Some boilers will evaporate a greater quantity of water per pound of fuel than others, thus producing steam more economically, but frequently the poor handling of an engine will cause the waste of a large quantity of water. From the averages shown in Table II on page 25 it will be seen that the water used per pound of coal is 7.49 pounds in the Southwest and 7.74 pounds in the Northwest. In California it is approximately 9.4 gallons of water per gallon of oil.

PLOWING CAPACITY OF TRACTION OUTFITS.

Certain factors governing the average acreage plowed daily or yearly have already been mentioned. This acreage is the output of the plowing equipment and crew, and in great measure it represents the success of the venture. It is the product of distance traveled in plowing and the width of the cut of the plows. The latter is governed largely by the power of the engine and by the soil conditions, but the former is influenced by a multitude of circumstances. The reports from 220 operators indicate an average working day for steam outfits of 11.27 hours, and the various engines have speeds ranging from 2 to 3 miles an hour. The average cut of moldboard plows in the Northwest is ascertained to be 11.18 feet, and of disk plows in the Southwest 13.2 feet. At 2.5 miles an hour the theoretical daily capacity of moldboard plows would be about 38 acres, and of disks about 45 acres. The daily average for the Northwest, using moldboard plows almost exclusively, is approximately 22.9 acres, and for the Southwest, using disk plows principally, 25.7 acres; hence, the actual performance is much lower than the theoretical capacity of outfits. Much of this loss is unavoidable, due to slippage of traction wheels and to time spent in turning and in taking on supplies. In the latter operation alone the loss of time may easily reach 25 per cent. Observation of steam outfits in the field shows that the time spent in taking on supplies varies with the crew and amounts to from five to fifteen minutes out of each hour. The importance of getting the greatest service out of the equipment is not always appreciated, especially by hired crews.

The tendency frequently is to attempt to secure high acreage by running at a high speed or by overloading the engine. The latter evil is the more common, the temptation to add an extra plow or a load of harrows often being too strong to resist. The effects of exceeding the maximum durable speed or load are to be seen in increased wear and breakage, with consequent delay, which overcomes any advantage gained by crowding the outfit. The reports received from operators do not distinguish clearly as regards performance between sod breaking and stubble plowing. Taking the data as a whole, it is found that approximately two-thirds of all operators harrow, disk, or roll the ground while plowing. The percentage is higher in the Southwest than in the Northwest, and in most cases somewhat greater power is used for this extra work, owing to the wider cut of plows. Of steam outfits 54 per cent and 27 per cent of one make of gasoline outfits reporting from the Northwest do other work while plowing, and 10 per cent and 3 per cent, respectively, of the total cost shown elsewhere may be charged to this extra work, basing the division on proportionate power consumption. Practically all these outfits use moldboard plows. The average nominal or tractive horsepower used in pulling plows only is 2.23 per foot cut for steam engines and 2.69 for gasoline engines. Therefore, 2.6 horsepower and 3.14 horsepower, nominal rating, are left, respectively, for each 14-inch plow bottom, after deducting the power used in pulling harrows, etc. In the Southwest 13 per cent of the power of the average steam outfit reported and 11 per cent of that of the average gasoline outfit reported are shown to be chargeable to work other than plowing. Of the steam outfits 70 per cent and of the gasoline outfits 80 per cent report extra work. After deducting the power thus consumed, 1.75 nominal horsepower per foot cut is expended by the steam outfits in pulling plows and 2.22 horsepower by gasoline outfits. This is based on the average width of furrow cut by the disk-plow outfits, as shown in Table II. From 8 to 10 inches is the usual cut per disk. From this it would appear that two or more plows should be dropped if harrowing is done, depending on the draft of the extra load, and that 10 moldboard or 15 to 20 disk plows are a load for the average steam engine, while the type of gasoline engine mentioned can handle fewer plows than steam engines of equal nominal rating. From 30 to 50 per cent more acres can usually be covered each day in stubble plowing than in breaking virgin sod, and the coal consumption to the acre averages less, though probably not in the same ratio. Sod breaking is usually shallower, and the heavier draft is overcome somewhat by the increased efficiency of the engine on the firm footing afforded by the sod.

In rush seasons night plowing is occasionally resorted to, as well as the use of two shifts between early dawn and late twilight. The latter is the simpler and more satisfactory method, but the difficulty of securing two efficient crews and the division of responsibility for accidents tend in either case to offset the doubling of the capacity.

Large daily acreages can not be secured in small fields, and few operators care to bother with jobs of less than 25 to 40 acres. Short furrows and frequent turns involve loss of time and a poorer quality of work. In fenced fields it is difficult to plow out corners by traction without special care and equipment, and frequently horses are employed for this purpose. This and the expense attached to moving make small jobs unprofitable. Forethought in attacking fields will reduce the area left unplowed by traction, and the manufacturers usually offer suggestions as to time-saving methods of laying out lands. The yearly acreage is influenced by all the foregoing factors of daily operation, also by the seasonal conditions, delays from disabling accidents, the amount of work to be had, and competition.

INCOME FROM TRACTION-PLOWING OUTFITS.

The apparent profit in steam plowing is so great as to encourage the reckless buying of equipment. From 30 to 40 acres is not an uncommon day's work and the mere running expense is often below $20. At prices ranging from $1.50 to $4 to the acre the daily income is apparently much in excess of operating expense, the factors of interest, depreciation, expense during idleness, and cost of moving often being overlooked. Keen competition is developed in some communities and the rate for custom plowing reduced to the point where only the most successful can make a profit. A study of the data given later as to the acreage plowed annually will show that, except in California, where holdings are much larger, the custom acreage is nearly or more than equal to the area plowed for the owner of the outfit. It follows, then, that even with all other factors favorable, financial success is doubtful where the custom rate is low.

The following table shows the range and average of custom prices, as reported by operators of both steam and gasoline outfits:

TABLE I.—*Prices charged for traction plowing in fifteen States and in Canada.*

Location of outfits.	Number of operators reporting.	Prices charged for plowing.		
		Lowest.	Highest.	Average.
North Dakota, South Dakota, Minnesota, and Montana	73	$1.25	$4.00	$2.99
Nebraska, Colorado, Kansas, Oklahoma, Texas, and New Mexico	116	.75	3.50	1.88
Indiana, Illinois, Iowa, and Missouri	6	1.00	2.00	1.44
California	12	1.25	1.60	1.32
Canada	23	1.75	5.00	3.66

The lowest figures are usually for stubble plowing and the highest for breaking sod, but the rates charged by the same operator for the two kinds of work are not as far apart as the range indicated. In parts of Kansas a difference of only 25 cents an acre is made, and a difference of 50 cents is reported by more operators in both Plains sections than any other figure. A difference of $1 or more is, however, common in the Northwest. In some cases these prices cover both plowing and harrowing, while in others from 10 to 25 cents an acre are added for harrowing. The prices in the corn belt and in Kansas, Oklahoma, and Texas (the average being $1.50 in Kansas and $1.62 for the three States) are so low as to leave little or no margin to cover expenses during idleness and net a profit. With all other factors equal, a slight increase in the rate will often turn an unsuccessful venture into a profitable one.

AVERAGE RESULTS WITH STEAM-PLOWING OUTFITS.

In view of the extreme variation in conditions encountered by individual operators, any averages of results must be taken with due regard for local conditions. The following table presents a summary of the data taken from reports complete enough to give the desired information. These include results for a part of the season of 1908. For the purpose of comparison, two columns are shown for Canada. The first is from direct reports from operators. In the second column averages are taken from the annual traction-plowing numbers of "The Canadian Thresherman and Farmer," from 1905 to 1909, inclusive, and represent 214 letters of steam plowmen in answer to that journal's annual circular letters on this subject. A small percentage of the letters are duplicated; that is, they are from the same operator in different years, and several correspondents reporting under column 1 are also found under column 2. The average of coal used given in column 2 is from 150 operators, many using either wood or straw or not reporting at all. Those using wood report about 2 cords a day as an average. The average number of barrels of water used by Canadian operators apparently varies greatly. However, a difference in standards may explain the variation. If the 72.8 barrels in column 1 were of 31.5 imperial gallons of 10 pounds each and the 57.1 barrels in column 2 were of 42 imperial gallons the water used per pound of coal would be 7.21 and 7.82 pounds, respectively. It is difficult otherwise to account for such a wide variation.

TABLE II.—*Data in reference to steam-plowing outfits operated in California, in the southwestern and the northwestern sections of the United States, and in Canada.*

Work accomplished, etc.	California.	Southwest.	Northwest.	Canada. 1.	Canada. 2.
Number reporting	11	100	60	23	214
Acres plowed annually for self	2,800	475	310	379	....
Acres plowed annually for others	689	580	348	628	....
Acres plowed annually, total	3,489	1,055	658	1,007	....
Percentage of custom plowing	20	55	53	61	....
Size of engine (horsepower)	[a] 110	26.46	27.5	29	27.28
Cost of engine	$5,500	$2,680	$2,505	$3,420	....
Number of plows [b]	23.3	....	9.58	11	8.6
Width of furrow cut (feet) [b]	20.45	12.8	11.18	12.83	10.03
Cost of plows [b]	$506	$451	$657	$860	....
Hours of work each day	10.6	11	11.44	12.31	....
Miles covered each day [c]	20.4	16.4	16.9	13.8	16.75
Acres covered each day	50.6	25.7	22.9	21.4	20.37
Days of plowing for the year	69	41	29	47	....
Men employed	6	3.43	4.24	4.11	4.46
Horses used	5.5	3.1	4.5	3.9	3.36
Labor and board (by day)	$16.50	$11	$14	$14	....
Quantity of fuel used each day [d]	7.16	2,508	2,735	3,151	3,064
Quantity of fuel used for each acre [d]	0.14	98.4	126.6	147.4	150.4
Cost of fuel for each day	$7.28	$6.91	$8.71	$8.34	....
Cost of fuel for each acre	$0.144	$0.273	$0.38	$0.39	....
Quantity of water used each day [e]	3,367	74.1	77.75	72.8	57.1
Cost of oil, etc., for each day	$1.00	$0.57	$0.59	$0.87	....

[a] Brake horsepower. Nominal or tractive rating about 60 horsepower.
[b] Less than one-fifth of the outfits reported in the Southwest use moldboard plows. These average 9.18 bottoms, cutting 10.7 feet, and cost $561 each. From 10 to 20 disk plows would be used to cut the average of 13.2 feet reported. These sets average $428 in price. The figures in the table are for the average of both types.
[c] "Miles a day" is miles traveled with plows in the ground, as figured from the daily acreage and the average width of the furrow. The distance traveled in turning, etc., is not included.
[d] For California expressed in barrels of crude oil; elsewhere in pounds of coal.
[e] For California expressed in gallons; elsewhere in the United States in barrels of 31.5 gallons.

The data for 1907 and 1908 under column 2 are much nearer the figures contained in first-hand reports from the Northwest and Canada, as is to be expected in view of the time covered by the latter. For these two years the averages of data contained in 118 letters show the size of the engine to be 27.7 horsepower; number of plows, 9.09; width of furrow, 10.6 feet; miles a day, 16.75; acres a day, 21.52; number of men, 4.53; number of horses, 3.57; quantity of coal a day, 3,245 pounds; quantity of coal for each acre, 150.8 pounds.

COST OF PLOWING WITH STEAM ENGINES.

In the following table the acre cost of plowing is based on the data in Table II. A considerable number of other operators were interviewed, but principally with regard to points not covered in the circular letters, their experience and results being on a par with those of the correspondents. It was found impracticable to separate the cost of harrowing in each report; hence, the corrected total for plowing alone is based on the percentages given under the discussion of acreage plowed on page 22.

TABLE III.—*Acre cost of steam plowing (including harrowing, etc.) in California, in the southwestern and the northwestern sections of the United States, and in Canada.*

Details of cost.	California.	Southwest.	Northwest.	Canada.
Interest on engine	$0.069	$0.098	$0.143	$0.131
Depreciation on engine	.158	.254	.381	.34
Repairs on engine	.08	.10	.10	.10
Interest on plows	.009	.024	.056	.048
Depreciation on plows	.015	.043	.10	.085
Repairs on plows	.02	.035	.066	.07
Interest and depreciation on miscellaneous equipment	.012	.037	.059	.039
Labor and board	.326	.428	.611	.654
Fuel	.144	.269	.38	.39
Oil, grease, etc	.02	.022	.026	.041
Total	.853	1.31	1.922	1.898
Corrected total		1.14	1.73	

The cost of men and teams on off days and of moving from place to place between jobs must be added to the cost per acre of plowing. This will frequently more than offset the correction for harrowing, the cost for each day of idleness being higher, of course, with steam than with gasoline outfits. The days of idleness are more frequent, possibly one in three, adding 10 to 15 cents per acre to the cost given. Since both breaking and stubble plowing are included, and in unknown proportions, no satisfactory statement can be made as to the relative cost of each. However, the daily running expenses are not essentially different; hence the relative cost is probably in inverse proportion to the daily acreage.

COMPARATIVE RESULTS WITH STEAM ENGINES OF DIFFERENT SIZES.

The following table shows fairly well what may be expected of steam engines of the small, medium, and large sizes generally used for plowing. Extremes are not represented. It will be noted that in the Southwest the medium-sized engines seem to be the most popular, and those of the largest size in the Northwest, while few small engines are used in either section. With the exception of the quantity of coal per acre in the case of small engines in the Northwest, the averages show the results that might be expected from the size of the engine, and in this case the number of operators is so small as to render the figures of little value. The number of men and horses evidently is not in proportion to the size of the engine. In both sections the small engines apparently travel more miles a day than the larger ones, this figure, as before, being calculated from the acreage plowed and the width of furrow. The figures as to horsepower per foot cut and the reciprocal "feet cut per horsepower" are quite significant, indicating that the larger engines furnish greater power per unit of nominal rating than the smaller. A comparison of sections on this point shows that from 20 to 25 per cent more power per foot of width is required in the Northwest than in the Southwest. The wider use of disk plows will account for a large part of this difference.

TABLE IV.—*Comparison of various sizes of steam-plowing engines used in the southwestern and the northwestern sections of the United States and in Canada.*

Details for steam outfits.	Southwest.			Northwest and Canada.		
	18, 20, and 22 horsepower.	25 horsepower.	30, 32, and 35 horsepower.	18, 20, and 22 horsepower.	25 horsepower.	30, 32, and 35 horsepower.
Number of outfits	10	42	22	5	21	41
Average size of engine	20.2	25	31.95	20.4	25	31.9
Width of furrow (feet)	9.15	12.25	16.67	7.5	10.23	13.2
Width of furrow (inches)	109.8	147	192	90	122.8	158.5
Men employed	3.6	3.43	3.76	3.8	3.95	4.39
Horses used	3.4	3.05	3.3	2.6	2.95	3.8
Acres covered each day	20.5	23.2	33.4	16.8	19.6	25.2
Miles covered each day	18.5	15.6	16.5	18.5	15.8	15.8
Horsepower per foot cut	2.21	2.04	1.92	2.72	2.44	2.42
Feet cut per horsepower	.452	.49	.521	.368	.409	.413
Pounds of coal used each day	2,350	2,457	3,218	1,780	2,552	3,100
Pounds of coal used for each acre	114.6	105.9	96.3	106	130.2	122.9

CABLE SYSTEM OF STEAM PLOWING.

In England, Germany, and other countries a common type of steam plowing involves the use of plows or other implements drawn by cables. A number of these outfits, all of foreign make, are used in various parts of the West, principally in California, and there chiefly on large sugar-beet ranches. So far as known, all of these outfits are of the double-engine type, a traction engine being located during operation at either side of the field. Steel cables, 80 to 100 rods long, attached to the implement, are wound on drums mounted beneath the engine boilers, the engines pulling alternately. In this way the entire power of the engines is available for work, none being used in moving their own weight across the fields. The engines advance alternately the width of the furrow, moving in parallel directions at right angles to the furrow. In many cases permanent roads along the sides of the fields insure a firm footing for the traction wheels. Balance plows are used, i. e., right and left hand moldboard plows are mounted in gangs facing a pair of large wheels. In plowing, the implement is not reversed, the forward gang being tilted out of the ground on one trip and plowing on the return. Frames to which harrows, rollers, etc., may be attached, cultivators, beet plows, and other implements for cultivation are a part of the equipment, and usually all tillage operations connected with the beet crop are accomplished without the use of animals.

Plowing is done at a depth of 12 to 14 inches for sugar beets, and in heavy adobe soil from 10 to 20 acres are covered per day. Light cultivation is done at a depth of 7 to 9 inches and deep tillage at from 14 to 16 inches, the cultivators being 16 feet and 10 feet in width, respectively. Cultivating is done at the rate of 25 to 35 acres and harrowing at the rate of 50 acres a day. A special implement, lifting 6 rows of beets at a depth of 12 to 16 inches, is used in harvesting, and from 15 to 25 acres are covered in a day when necessary. No time is lost in taking supplies, as the engines are stationary, and little time is wasted at the ends of the furrows, one engine being ready to start pulling as soon as the other finishes.

From five to eight men are used in plowing, including a foreman, two engineers, one or two teamsters, two plowmen, and a cook. From 6 to 8 barrels of crude oil daily supply both engines. The expenses, not including interest and depreciation, are about $30 a day, or from $2 to $3 an acre. In comparing this with the cost of operating direct traction outfits, the great difference in depth of plowing must be kept in mind. Interest and depreciation charges are heavy, though the outfits are in use the greater part of the year. The investment for each outfit, including freight and duty, is from $25,000 to $30,000. The cables, which cost from $600 to $900 each, last from six to eighteen months in continuous use, and bad water destroys flues in from six to twelve months; otherwise the outfits are capable of long service.

In view of the heavy initial and operating cost, the use of this equipment is restricted to large enterprises. One ranch in California uses five sets of tackle in handling 10,000 acres of sugar beets, using horses only in seeding and hauling. Each outfit is said to displace 120 horses and the necessary drivers. Another outfit, operating eleven months in the year, handles 1,300 acres of beets. Others are to be found in large vineyards, while a large number are used in sugar-cane culture in Hawaii. While these outfits are not suitable for use on a small scale it would seem that a modification, embodying numerous advantages and adapted to more general use, might be produced in the United States and sold at a price within the reach of small operators.

INTERNAL-COMBUSTION ENGINES.

Internal-combustion engines, represented by gasoline and kerosene motors, are usually of smaller size than the steam engines used for plowing. They range from 12 to 40 horsepower, nominal rating, and from 19 to 80 horsepower, brake rating. As before explained, the nominal rating is supposed to denote the equivalent of the work of the number of horses specified which is performed by the engine, while the brake rating indicates the power of the engine for belt work. In size internal-combustion engines range from a weight of a little more than 2 tons to 17 or 18 tons, although the majority in use are between 5 and 10 tons. As a rule, they are rated higher in proportion to actual brake horsepower than are steam engines, but have a higher tractive efficiency than the latter; that is, deliver a larger proportion of the total power in effective pull. The same confusion as to rating prevails and, owing to the differences in the practice of various manufacturers, gasoline engines are frequently expected to do more than their actual horsepower warrants. In price these motors are usually more expensive per brake horsepower than steam engines, the types most used ranging in cost from $1,300 to $2,500 delivered free in territory within reasonable distance from the factories.

Gasoline engines, using this term to designate all of the oil-burning internal-combustion class, present a great variation in type, having so recently been developed as to lack the standardization possessed by steam traction engines. The four-cycle motor is universally used.[a] Most of the smaller tractors are of the single-cylinder type, which is the most economical of fuel but not so steady in running as multiple-cylinder types, on account of the longer interval between power strokes. On account of the limitations to the size of cylinders this type must necessarily continue to be made in small units, the more powerful tractors now on the market using two, three, or four cylinders. These may be either vertical or horizontal, and if horizontal either "twin" or "opposed," i. e., either side by side or in line on opposite sides of the crank shaft. The larger the number of cylinders the more complicated the motor, but usually the more smooth running, owing to the more nearly continuous succession of power strokes. Two opposed pistons in a single cylinder are used on one type. The variation in engine speed is considerable, ranging from 220 to 1,600 revolutions a minute, but as a rule not over 550 revolutions are made at normal speed. Differences in the method of governing, ignition, reversing, and cooling are notable, the latter including air, water, oil, and steam cooling devices. Practically all tractors are gear driven, but great variation as to the height and width of traction wheels is found.

A few types are equipped for burning either gasoline, kerosene, or distillate (low-grade kerosene), although no motor has as yet been developed which will handle the different fuels equally well under all conditions. Distillate is largely used on the Pacific coast, but is not easily obtainable in other sections. Kerosene is used to a great extent in at least one of the leading plowing tractors. Both kerosene and distillate are cheaper by the gallon than gasoline, and reports from correspondents indicate that the fuel cost per acre is less also.

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[a] For an exposition of a four-cycle motor, see Farmers' Bulletin 277.

Alcohol is not as yet a commercially important fuel for traction engines. Opinion as to the relative merits of kerosene and gasoline is divided. The former may be used successfully where the engine is operating under a full and rather constant load, as in plowing, but owing to its heterogeneous composition it does not give such perfect combustion under varying conditions as does gasoline. As a rule, from 1 to 2 gallons of the latter are used per day for starting and warming up the kerosene motors; hence its use is seldom entirely dispensed with. The rapid development of internal-combustion engines for marine, automobile, traction, and stationary purposes has increased the demand for gasoline and the rate of exhaustion of the supply, so that it seems only a question of time when the less volatile oils will of necessity be used extensively in tractors. For the present, however, gasoline remains the standard fuel and the majority of new tractors are being designed primarily with a view to its use.

COST OF PLOWING WITH GASOLINE ENGINES.

As is the case with steam engines, the practice of using gasoline motors for plowing is so new that satisfactory figures regarding life, repairs, etc., are not to be had. It follows, therefore, that figures on the cost of plowing are not conclusive except as regards the expenses which may be designated as current. The first successful gasoline tractors were put on the market about 1903, and comparatively few have been out long enough for operators to become thoroughly familiar with what may be expected of them, yet the figures given in the following pages may be taken as indicative of their practicability.

With regard to the factors of interest and depreciation the same general points will apply to gasoline as to steam engines. It is doubtful whether the comparative wear in plowing and thrashing will be in the same proportion as with steam engines, as the gasoline engines are less likely to be overloaded in plowing. Gasoline engines when first developed were stationary and could be rated on the same basis as stationary steam engines or in comparison with horses on a small horsepower. Later on, some of these same engines were mounted on traction trucks and given the same rating as before. This naturally confused purchasers, who expected these engines to draw the same load as steam engines of equal rating. Serious disappointment to the users and damage to the tractors were the result. A few makes of gasoline tractors were given a nominal rating, based on the number of horses which they would equal in effective pull, though the various manufacturers took different bases for their ratings. Operators soon found that gasoline tractors could not be forced beyond the maximum of power developed at the time of explosion, and were not to be relied upon for getting out of serious difficulty when already pulling a full load. On this account it is probable that gasoline engines as a whole pull loads more suited to their normal and durable power than do steam engines. On the other hand, owing to the smaller margin of brake horsepower over and above the nominal rating, they are more likely to be crowded to their limit in running separators or other machines driven by belt power. A leading manufacturer of gasoline engines estimates the wear and tear at 70 and 30 per cent, respectively, for plowing and thrashing, when given equal length of service. Other authorities who have given thought to this point are of the opinion that, with the exception of such makes as have a low nominal rating in proportion to actual horsepower, gasoline engines as a class will be worn almost equally by plowing and thrashing. Taking the whole class of gasoline tractors, it is probabl that a division of wear and tear and interest on the basis of 60 and 40 per cent for the two operations will be as accurate as can be assumed at this time.

The life of gasoline tractors will at present depend very largely upon the make, owing to the large number of experimental machines which are being offered. However, since the data contained in this bulletin are taken only from those makes of tractors which have demonstrated for several seasons their practicability in the hands of a number of operators, the assumptions made in connection with the life and service of steam engines may be repeated here and the same rate of interest and depreciation taken. Estimates from a number of operators of the internal-combustion tractor now in most common use place the life of the outfit at ten years, and although this is probably in excess of the actual service the exact figures can not be determined, as practically none of the standard outfits have been abandoned on account of wearing out.

Repairs to engines are estimated at 10 cents an acre and $100 a year, respectively, by two officials of the company making the tractor just mentioned, these amounts being deemed ample to keep all parts in perfect order and recommended as being economical expenditures on the part of the purchaser. The former figure supports the estimates of several correspondents and may in this case be fairly assumed as correct. The plows used are of the same type as those employed with steam engines, though of course fewer in number, and the plow repairs will be proportionately less. The cost of miscellaneous equipment will usually be covered by $100, as provision must be made for but two men and the transportation of a comparatively small quantity of fuel and water.

The labor cost of operating gasoline outfits is usually limited to the wages and keep of two men, one for the engine and one for the plows. This is true regardless of the size or make of the tractor. Horses are used but a few hours a week, if at all. In many sections gasoline is delivered in the field by the dealer, horses thus being dispensed with entirely. Licensed engineers are not usually required with gasoline outfits, and consequently the labor rate is usually lower than with steam outfits. The cost of maintenance is of course less, and $7 a day for the wages and board of the two men required will probably cover all but a very few cases. The figure allowed for labor includes the wages of a first-class engineer, as, notwithstanding the simplicity of gasoline engines, skilled labor is as essential to the best results as with steam engines. Board is allowed at the rate of $1 per day, and a small charge for the occasional use of a team may easily be covered by the figure given for labor cost. The other items of cost as figured from the reports of twenty-six correspondents using one of the leading plowing tractors are given in the following table of averages. The column headed "Canada" includes reports from eleven Canadian operators of this same tractor, published by "The Canadian Thresherman and Farmer" in its annual plowing numbers from 1905 to 1909, inclusive.

Table V.—*Data in reference to gasoline-plowing outfits operated in the southwestern and the northwestern sections of the United States and in Canada.*

Work accomplished, etc.	Southwest.	Northwest.	Canada.	All outfits.[a]
Number of outfits	10	11	11	26
Acres plowed annually for self	479	335	....	399
Acres plowed annually for others	362	300	....	316
Acres plowed annually, total	841	635	....	715
Percentage of custom plowing	43	47	....	44
Size of engine (horsepower)	22	22	22	22
Cost of engine	$2,254	$2,300	....	$2,300
Number of plows used [b]	12	6.77	7	....
Width of furrow cut (feet) [b]	8.83	7.9	7.93	8.18
Cost of plows	$347	$244	....	$294
Hours of work each day	10.1	10.55	....	10.23
Miles covered each day	17	18.25	16.8	17
Acres covered each day	17.4	17.5	16.1	16.94
Days of plowing for the year	48	36	....	42
Men employed [c]	2	2	2	2
Labor and board (by day) [c]	$7	$7	....	$7
Quantity of fuel used each day (gallons)	53.6	49.4	[d] 50	49.2
Quantity of fuel used for each acre (gallons)	3.08	2.8	[d] 3.1	2.9
Cost of fuel for each day	$5.26	$7.31	....	$6.27
Cost of fuel for each acre	$0.302	$0.418	....	$0.37
Cost of fuel (gallon)	$0.098	$0.147	....	$0.1275
Cost of oil for each day	$0.505	$0.462	....	$0.487

[a] Data from correspondents only, including several scattered outside of the two principal sections.
[b] The figures for the Northwest are for moldboard plows and for the Southwest for disk plows; the average of all outfits includes both.
[c] Two men were reported in all but a few cases, and this number was recommended as a most satisfactory crew. No horses are included, as the reports indicate their use for only a few hours each week, if at all.
[d] United States gallons.

The following table, showing in detail the estimated cost of plowing with gasoline tractors, is based upon the foregoing averages and assumptions and should be analyzed rather than taken as a whole. Harrowing or similar work is included in 27 per cent of the cases in the Northwest and in 80 per cent in the Southwest.

TABLE VI.—*Acre cost of plowing with gasoline engines (including some harrowing) in the southwestern and the northwestern sections of the United States.*

Details of cost.	Southwest.	Northwest.	All outfits.
Interest on engine	$0.103	$0.139	$0.124
Depreciation on engine	.214	.29	.257
Repairs on engine	.10	.10	.10
Interest on plows	.023	.022	.023
Depreciation on plows	.041	.038	.041
Repairs on plows	.034	.057	.041
Interest and depreciation on miscellaneous equipment	.009	.012	.011
Labor and board	.402	.40	.413
Fuel, usually kerosene	.302	.418	.370
Oil, etc	.029	.026	.029
Total	1.257	1.502	1.409

As in the case of steam outfits, a portion of this average cost, based on the horsepower estimated to have been consumed, is chargeable to harrowing and other operations. This is ascertained to be 3 per cent in the Northwest and 11 per cent in the Southwest; consequently, the corrected acre cost of plowing only should be $1.457 and $1.119, respectively. However, no charge for the labor and cost of moving has been included, nor for labor on days when owing to bad weather or breakage no plowing was done. In most cases the crew of two men of a gasoline outfit could more easily find employment elsewhere during unfavorable weather than the larger crew of a steam outfit, and, as has been pointed out, fewer idle days from this cause are the rule, owing to the lighter weight of the engine. Perhaps one day in four would be a fair estimate of time lost from all causes. If the expenses of a 5-mile move, together with the board and a half day's wages of the two men, are allowed on each idle day, the extra expense to be borne by each day of productive labor would be from $1.75 to $2, or from 10 to 13 cents an acre, thus offsetting the reduction for harrowing.

The following table includes data furnished by operators in the Northwest on three types of gasoline tractors, distinguishing between breaking sod and plowing stubble as regards fuel consumption and acreage per day. In the case of the two-cylinder tractor the mean between breaking and plowing is given for the purpose of comparison with the figures presented in Table V.

TABLE VII.—*Comparative performance of gasoline tractors in breaking and plowing in the northwestern section of the United States.*

Details of cost, etc.	Two cylinder, 22 horsepower.[a]			Four cylinder, 30 horsepower.[b]		One cylinder, 20 horsepower.[c]	
	Breaking.	Plowing.	Mean.	Breaking.	Plowing.	Breaking.	Plowing.
Gallons of fuel used each day	51	51	51	45.1	43	24.2	26.8
Gallons of fuel used for each acre	3.32	2.26	2.79	3.42	2.29	2.28	1.94
Average price of fuel (gallon)	$0.151	$0.141	$0.146	$0.16	$0.16	$0.16	$0.16
Cost of fuel for each day	$7.72	$7.20	$7.46	$7.24	$6.87	$3.87	$4.28
Cost of fuel for each acre	$0.512	$0.318	$0.415	$0.548	$0.366	$0.365	$0.31
Cost of labor for each day	$7	$7	$7	$7	$7	$7	$7
Cost of labor for each acre	$0.465	$0.31	$0.388	$0.53	$0.372	$0.66	$0.507
Cost of labor and fuel for each acre	$0.977	$0.628	$0.803	$1.078	$0.738	$1.025	$0.817
Cost of oil for each acre	....	....	....	$0.06	$0.043	....	....
Number of plows used	....	....	....	5.63	8.1	4.25	6
Width of furrow cut (feet)	6.52	10.14	8.33	6.57	9.45	4.96	7
Horsepower per foot cut	3.37	2.17	2.77	4.57	3.17	4.03	2.86
Acres covered each day	15.06	22.60	18.83	13.2	18.8	10.6	13.8
Miles covered each day	19.05	18.60	18.83	16.6	16.4	17.6	16.3

[a] Number of reports received, 9. [b] Number of reports received, 15. [c] Number of reports received, 10.

The two-cylinder tractor is frequently operated with kerosene, and hence shows a lower average price per gallon of fuel. Labor is assumed at the rate of $7 a day, although this is in excess of the average reported by the majority of operators. It will be noted that the acreage in plowing is 150, 142, and 130 per cent, respectively, of that in breaking, while miles a day and the daily consumption of fuel are practically the same. The labor cost would remain the same for both kinds of work, and since the engine is usually loaded approximately the same in either case the daily figures for interest and for wear and tear would remain stationary. The variation in plow cost is so slight that for practical purposes the comparative cost of breaking and plowing can be considered as in inverse ratio to the width of furrow cut. Taking 1.4 as the ratio between the acreage in plowing and that in breaking, and assuming the daily expense to be the same in both cases, the figures shown in Table VI would indicate that without harrows attached the outfits in the Northwest break prairie at a cost of $1.70 an acre and plow in stubble at $1.214, while those in the Southwest accomplish the work at rates of $1.466 and $1.05 an acre, respectively.

COST OF PLOWING WITH HORSES.

The cost of plowing with horses under conditions obtaining on three groups of farms in southeastern, southwestern, and northwestern Minnesota, averaging, respectively, 166.9, 297.06, and 378.26 acres, is published in Bulletin No. 73, Bureau of Statistics, United States Department of Agriculture; also the cost on a single farm of 1,820 acres in northwestern Minnesota, the data from which are not included in other averages. The figures cover a period of six years, from 1902 to 1907, inclusive, and a cultivated acreage of approximately 5,000 acres a year. The average annual cost of keeping a work horse in the grain-growing section is ascertained to be $65.23 on the large farm mentioned and $75.07 on small farms averaging 378 acres each. The cost per hour of horse labor for all sections is as follows: Southeastern farms, 9.25 cents; southwestern, 8.36 cents; northwestern, 7.32 cents; on the large farm, 7.46 cents. The average annual cost given is divided by the average number of hours' work done annually by each horse and includes the following items: Interest on investment, depreciation, harness depreciation, shoeing, feed, labor, and miscellaneous expenses. On the smaller farms in the northwestern section each horse worked on an average only 3.14 hours per workday throughout the six-year period, and on the large farm somewhat less. The bulletin says:

In order to have motive power available at seed time and harvest, the farmer is obliged to feed and house horses through seasons of practical idleness. The average annual cost of maintaining a farm work horse is approximately $80, and for this cost of maintenance the animal gives a return in work of about three hours a day throughout the year.

The cost of man labor is ascertained in the same detailed manner, the hours of both man and horse labor being a matter of daily record. The cash and labor repairs on plows are matters of careful record, and interest and depreciation are based on annual inventories. Since conditions in the northwestern part of Minnesota are like those of the grain-growing sections of the Dakotas, and especially the Red River Valley, the figures for this section are of more value in this connection than those from the southern part of the State. Including charges for man and horse labor and for plow values consumed, the cost of horse plowing in stubble land is stated in the bulletin to be as follows:[a]

Location of farms.	Fall plowing.				Spring plowing.			
	Total acres. 5 years.	Labor cost.	Plow cost.	Total cost.	Total acres. 5 years.	Labor cost.	Plow cost.	Total cost.
Southeastern Minnesota	4,773.4	$1.256	$0.086	$1.342	803.3	$1.311	$0.086	$1.397
Southwestern Minnesota	5,973.6	1.141	.132	1.273	1,413.2	1.171	.132	1.303
Northwestern Minnesota	7,186.0	1.130	.078	1.208	925.9	1.186	.078	1.264
Large farm, Minnesota	5,363.5	.924	.061	.985	526.0	.973	.061	1.034

The average cost per acre of 23,296½ acres of fall plowing was $1.201; of 3,668⅖ acres of spring plowing, $1.258; and of 26,966 acres of both fall and spring plowing, $1.209 an acre.

[a] See Tables XXXIX and XI, Bulletin 73, Bureau of Statistics, U. S. Dept. of Agriculture.

In the northwestern group of farms 72.53 acres were broken by horses at a cost of $106.60 for labor. By adding the plow cost, the total is found to be $1.546 per acre. An earlier bulletin[a] dealing with this same investigation shows the cost of man and horse labor in breaking a small acreage in southwestern Minnesota in 1902, 1903, and 1904, to be $2.18 per acre, and the average labor cost in breaking tame sod to be $1.67 in southeastern and $1.42 in northwestern Minnesota, respectively. An average plow cost of $6\frac{4}{5}$ cents per acre should be added to these figures in comparing them with the cost shown for traction plowing. Gang plows and other large machinery are not used to any extent in the southeastern group of farms. On the large grain farm in the northwestern section the use of gang plows in large fields free from stone is shown in the reduced cost of plowing, even though the rate per hour of horse labor is higher than on smaller farms in the same neighborhood. Leaving out the plow cost, which is much greater in the case of engine gang plows, the showing is more favorable to the tractors as a source of motive power. The average cost of horse plowing will be reduced by $8\frac{9}{10}$ cents and of traction plowing from 12 cents for gasoline to 20 cents for steam by not considering the plow costs. The housing of the horses and tractors has not been considered in any of the foregoing figures, and of course this would be much cheaper in the case of tractors. Traction plowing, especially with gasoline engines, can apparently be made to approach the cost of plowing with horses if done on a large scale, but too much reliance can not be placed on the figures assumed for the depreciation of outfits. As before explained, it is impossible to present dependable averages for depreciation, owing to the recent development of the industry. On the whole it can hardly be said that traction plowing is cheaper than horse plowing, especially where horse gang plows are used, though it may be made so under favorable circumstances.

PRACTICABILITY OF TRACTION PLOWING.

No general statement as to the practicability of traction plowing can be made, as the factors involved are too many and too varied to admit of general conclusions, even for a single locality. Any one of the factors previously discussed may determine the success or failure of an outfit. Many localities are generally unsuited to the practice, but a few operators may have remarkable success because of favorable environment or unusual ability. If season, soil, and topography are favorable and fuel and water are convenient it becomes largely an individual problem. The size and cost of equipment, the acreage to

[a] Bulletin 48, Bureau of Statistics, U. S. Dept. of Agriculture, and Bulletin 97, Minnesota Agricultural Experiment Station.

be plowed, the cost of operation, the competition encountered, and the energy and ability of the operator are all important factors materially affecting any conclusions which may be drawn from averages.

Two widely varying points of view are encountered with regard to the practicability of traction plowing under any given conditions, namely, that of the landowners and that of the custom operators. The former have an interest in the crop beyond the mere cost of plowing the ground in preparation for it, and it is safe to say that the majority of these have decided the question on the basis of net returns. In many cases it was found that approximately half the number of horses kept before the purchase of a tractor were still required for such operations as drilling, harvesting, and hauling. Though in such cases the use of the engine was limited to from forty to eighty days of plowing and thrashing and the value of the horses displaced would seldom equal more than two-thirds the cost of the engine, the consensus of opinion was that the availability of power at the time when it was imperatively needed justified the added investment and cost of operation. Handling a large acreage and getting work done at any cost were first considerations with many owners of large farms, and practicability in such cases is not determined by comparisons with the cost of operation by horses, even though this is undoubtedly larger in newer sections than in those for which figures are quoted. The common rate for horse plowing in the older sections of the Dakotas is $1.50 per acre, but during rush seasons the figure has no significance, as little or no horseflesh is to be hired at such times.

For the improvement of raw land by breaking, traction outfits probably have an advantage over horses in cost of operation. Even if this were not so, the increase in value of the land due to breaking and seeding is sufficient to pay a handsome profit on every acre turned, and owners have taken advantage of this to an amazing extent. One quarter section in South Dakota, for instance, is said to have been broken this year in twenty-two hours, three steam outfits working continuously in order to accomplish the feat. A six-horse team with an ordinary gang plow would have required practically a month, Sundays included, to do the same work. After land is once broken, however, many owners consider it cheaper to plow with horses, and until the introduction of the small general-purpose motors traction-plowing outfits were most popular in newly developed areas. The cost of both horse and traction plowing will vary widely, and the averages presented do not represent the extreme possibilities of either. Many reports have been received from operators who consider traction plowing an absolute failure, and many from men who apparently have had great success with it; hence, the difficulty of approving or condemning the practice without a full knowledge of local conditions.

The operator who depends largely or wholly upon outside work is more immediately concerned with the cost of plowing than the landowner, as profits must come from the difference between the cost and the custom rate. It has been shown that of the acreage plowed by correspondents the custom-plowed area is nearly or more than equal to that plowed for the owners of the outfits. A comparatively small number do custom plowing exclusively and few outfits are maintained entirely for use on the owner's land, though the latter are said to be increasing in number with the adoption of smaller gasoline tractors. The smaller percentage of custom plowing reported by the gasoline operators also indicates that more steam outfits are kept mainly for custom plowing, and in sections where the custom rate is low it is doubtful whether any but the most successful can make a fair profit. In August, 1908, at one point in western Kansas, a local coal dealer reported that fourteen steam operators were doing custom work at the current rate of $1.25 for plowing and harrowing stubble land, and of the fourteen there was but one to whom he would extend credit on fuel. In this case competition, not with horses but between traction outfits, had forced the price per acre down to the point where if reasonably good work were done only excellent management and good luck could net a profit. The custom operator must usually pay a higher rate of wage than the farm owner, as the latter can give continuous employment during the month, while the former commonly pays his help only for days actually worked. Disabling accidents represent a total loss of time and income to the custom operator, but the farm owner is seldom wholly dependent on his engine for plowing and can make some headway without it.

The purchaser of a custom outfit assumes a considerable risk, and if ample margin between the cost and the custom rate is not to be had he invites failure in case of unfavorable circumstances. In estimating the yearly acreage required to make such a venture profitable, a separation of costs into fixed and variable items is necessary. Supposing the daily capacity of the outfit to be known, the items for fuel, labor, repairs, and oil may be reduced to a fixed acre cost. Table III indicates a total of $1.183 for these items for steam outfits in the Northwest doing both plowing and thrashing. If this figure and the ratio between the cost of breaking and that of plowing previously suggested be assumed as correct, these items would amount to $1.38 for breaking and $0.986 for plowing. Calculating interest and depreciation on engine, plows, and miscellaneous equipment as before and assuming that they will remain constant with a reasonable variation in acreage each year, the annual total chargeable to plowing would amount to approximately $486. On the basis of the 658 acres per outfit shown on a previous page the overhead charges would be 74 cents an acre. However, if it is desired only to meet the custom rates of $1.50 for plowing and $3 for breaking prevailing in parts of the Dakotas, the necessary acreage may be approximated by dividing $486 by the difference between $1.38 in one case and $3 in the other. This method gives 945 acres of plowing or 300 acres of breaking as the volume of work which will under the foregoing conditions pay operating expenses and cover interest and depreciation. This would require from sixteen to twenty days of breaking or thirty-five to forty days of plowing, without taking into account expenses on off days or in moving. Since the breaking season in this section is usually of at least six weeks' duration and the plowing season of equal length after the thrashing season, it can be seen that with good weather and management the plowing venture may be a financial success. It can not be too strongly emphasized, however, that the practicability of such a venture depends largely upon an undetermined factor, namely, the life of the outfit. The overhead charges suggested are based on an assumption in this regard that may prove to be wrong in general and certainly will not be true in every individual case. For this reason in particular the custom operator's venture is attended with considerable risk of failure, and better care than is usually given to farm machinery should be used in extending the life of a costly plowing equipment over a profitable period of service.

Granting the practicability of traction plowing under given conditions, the selection of equipment, and especially of the tractor, is a vital point. Plows for this work are in the main satisfactory and, being confined to comparatively few makes, are more easily investigated. However, the large and rapidly growing number of traction engines offered for sale makes selection difficult. To be practicable the tractor must be powerful, durable, economical, and simple, with emphasis on all four points. It must draw a profitable load continuously while at work and that without excessive depreciation and repair charges. It must be economical of fuel and labor and not so complicated as to require skill not readily acquired by the average farmer. In addition to serviceability in plowing it should be adapted to a wide range of usefulness in order to compete seriously with the horse as a source of motive power.

As to size, it may be said that for plowing alone and where work is abundant and delays few, the largest engines are the most economical, as the cost of labor and the interest and depreciation may be distributed over a larger acreage. However, the larger the outfit the longer the period of delay occasioned by wet weather and the more limited the sphere of usefulness. A larger acreage must be provided to utilize the plowing capacity of the engine, and in other work, such as thrashing, hauling, disking, harrowing, seeding, etc., frequently economical use can not be made of the power of the largest engines. The smaller engines are less economical of fuel and labor, but being better adapted to a variety of purposes reduce the overhead charges through increasing the days of service rendered.

Both steam and gasoline tractors have their advantages for this work. The former are more advanced as a class and are built in larger units, and hence are popular where conditions demand great power, as in breaking large acreages. Reference has already been made to the matter of rating engines, the steam engines as a class having a larger reserve power over the nominal rating than gasoline engines and greater tractive efficiency per nominal horsepower. On the other hand, gasoline tractors, possibly on account of size, can usually transform into effective pull a larger percentage of the power actually developed than can steam tractors. No great difference in weight per actual brake horsepower exists, but a slight advantage in favor of gasoline tractors as to weight per actual drawbar horsepower was indicated as a result of competitive tests at Winnipeg in July, 1909. Both, it may be said, were considerably below the horse in weight per unit of pulling power, and of course had a still greater advantage in driving stationary machinery. A greater weight of supplies must be carried by steam engines, this, of course, adding nothing to their strength. Gasoline engines are usually capable of longer runs without replenishing supplies, and less time is therefore lost on this account. They have the advantage in being quickly started and in not consuming fuel when not at work. The matter of supplying fuel is simpler and the expensive process of supplying water is reduced to a minimum. Internal-combustion engines as a class convert into work a much greater proportion of the thermal units in fuel than do steam engines, but present types are restricted in the kinds of fuel which can be used to advantage. Steam engines use a wide variety of fuels with little difference in efficiency and are consequently less dependent on limited sources of supply.

Aside from the foregoing considerations, the essentials are practically the same for both types. Strength must be a prime feature of a successful farm motor. This applies particularly to frame and traction gearing. The latter should be of steel or semisteel, wide in face and bearing, and of the best workmanship. The gearing should be absolutely protected from dust, as should all bearing surfaces. The gears probably more than any other parts are subject to wear and breakage and should receive great attention from both manufacturers and purchasers. They should be in perfect alignment at all times to prevent unequal wear, followed by strain and breakage. Rigidity of frame and wide bearings tend to effect this alignment, yet in so far as is possible flexibility should be allowed in order to minimize the effect of rough ground. Jolting should be transmitted as little as possible to moving parts mounted on the boiler frame. Perfect lubrication is necessary, and all parts of the engine should be easily and instantly accessible for repairs or adjustment.

The traction wheel is a fundamental point. One authority states that in building a tractor he would first build the wheel and then the engine. The wheel must be either wide enough or high enough to support the weight of the engine on soft ground and to distribute it under all circumstances without undue packing of the soil. Some tractors already rival the horse in the matter of weight per unit of bearing surface. Besides width and height there must be a proper arrangement of lugs on the surface of the wheel in order that it may grip the soil firmly and still not clog. Great loss of power may occur in this simple point of application. Types of wheel composed of independent pedals are being developed, with a view to reducing the loss through slippage.

In general it may be said that the progress made in the last six years in the development of both steam and gasoline tractors has been remarkable and that the concentration of capital and thought upon the problem of supplying practicable farm motors gives promise of even more rapid progress in the next decade. When it is considered that during the long era of development of farm machinery no radical improvement has been effected in the animal as a source of motive power, it is not surprising that the early history of plowing by mechanical prime movers does not show a general advantage in economy over ordinary methods. The animal as a motor has many advantages which must be overcome before the universal introduction of mechanical substitutes, and the latter is not imminent. However, the increasing purchase and use of smaller tractors by western farmers, not only in grain-growing sections but on larger farms in the corn belt, indicate that practical men are finding profitable employment for a general-purpose farm engine. So long as large areas of prairie remain to be broken there will be a field for the large plowing engine developed for that purpose alone, but the activity displayed by inventors and manufacturers justifies the expectation of dependable farm motors, varying in type and size, adapted to a much greater variety of work than that in which they have hitherto been chiefly employed.

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