Minnesota Bulletin 250 January 1929

UNIVERSITY OF MINNESOTA
AGRICULTURAL EXPERIMENT STATION

STONING FARM LANDS

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By M. J. Thompson and A. J. Schwantes

INTRODUCTION

Land clearing in Minnesota consists largely in the removal of stumps and brush. In some parts of the state, however, stone removal constitutes an important part of the problem. In parts of the cut-over district both stumps and stones must be removed to prepare the land for cultivation, and occasionally the stones require more effort than the stumps. In the southern and western parts of Minnesota many fields that are entirely free from stumps and brush must be cleared of stones before they can be successfully cultivated, and many fields throughout the state can be greatly improved by removing stray boulders.

Until 1920, stone removal in land reclamation and farm management was one of the few unexplored fields of American agriculture. It has been considered a disagreeable job, perhaps unworthy of consideration, and one in which present practices could not be improved upon. Little or no organized thought had been expended upon standardizing the practices involved in stoning lands or in working out the mechanical and economic relations involved.

War salvaged explosives have had a widespread influence. The first and most obvious effect was to increase the number of uses for explosives and to expand the volume used. It has been revealed that there is a land reclamation job in every county, almost on every farm, on the prairies as well as in the timbered belt, for both were glaciated. In making possible the cleaning up of odd acres on old farms, removing tramp stumps or scattered boulders or beds of smaller rock, the war explosive made a distinct contribution to good farm management. Increased use brought troublesome questions. Investigation alone could provide adequate reply.

Farm practices and the mechanics of stoning land came first under observation. Questions arose as to which implement is better and when —the standard farm wagon, the dump wagon, the low stone wagon, or the sled. What is the standard load and the cordage removed by each in a given distance or a given time? What are the best handling devices? These studies constituted an attempt to standardize practices in stoning land. Next in importance was the comparative economy of

[1] Most of the material presented in this bulletin was derived from data gathered on experimental plots by members of the Division of Agricultural Engineering—Clarence E. Johnson, Donald Hammerberg, Chester Christgau, J. J. McCurdy, A. Dell Wilson, and B. H. Gustafson. Much credit is due to the farmers who co-operated in clearing the plots.

Mrs. Dorothea D. Kittredge assisted with the derivation of the formulas for determining the size of charge necessary for stone blasting.

mechanical and explosive power; the disposition of stones by burying them or by filling ravines; the relative value of thoro stoning in advance of breaking or removing the large surface rocks only; mechanical means for collecting small stones.

The mechanics of stone removal opens the question of stone land utilization, and its economic relationships must be considered. Just where does the marginal zone begin? At what point, with what system of farming, perhaps with what crop, should stoning be suspended? What size and kind of stones and what amount of stone per acre will allow land to pass from a tilled crop to a grass crop; from grazing to forest husbandry?

The sudden emergence of an occasional large rock at the bottom of the furrow, becoming more troublesome annually to the plowman, when the land has been seemingly stone free and farmed for ten years, raises a new question. How do the rocks come up? Is it through the heaving action of frost or because of erosion? Both wind and water exert a readily discernible influence upon our tilled lands. At Duluth and elsewhere, in both sand and clay, semi-annual readings are being taken of rock buried at varying distances in order to determine displacement, if any, by frost or other agency. The stone history of new land at the Duluth station is being recorded in terms of labor units expended in removing stones, cordage harvested at the first picking, coincident with the first breaking, and in successive stone harvests of later years. On the 3-, 4-, and 5-year rotations, located on land farmed for nearly 15 years, the stone is picked after the tilled crop is harvested and the cordage is then determined. Does the more frequent plowing of the short rotation stimulate erosion and expose more stone? The various experiences raise the question of costs of stoning in reclamation and later in management and operation of land. Stone in land was once considered an absolute liability. It is now used for blind ditching, for road and floor beds, and for fills. Stones make an admirable surface foundation for outbuildings, to neutralize the heaving action of frost in heavy soil. Such use is common and successful at Duluth. They still are used as filler in concrete walls, and are crushed and mixed with cement. Powdered rock of granite origin enters extensively into highway construction. There has been a gradual transition from liabilities to assets.

METHOD AND SCOPE OF STUDY

The data presented in this bulletin were gathered from plots in several parts of the state. Each plot was completely cleared and the land was prepared for a crop. The plots varied slightly in size but averaged about half an acre. At Askov, 6 acres were cleared on two farms; near Guthrie, 4 acres were cleared; and near Duluth, 2 acres. The tracts selected were representative of conditions in those sections of the state.

The work was done by representatives of the Division of Agricultural Engineering, co-operating with the land owners, who furnished the teams and most of the equipment, and in most instances some of the necessary labor.

The data on the removal of large boulders were obtained from several hundred boulders blasted near Hibbing and from work done with scattered boulders near Guthrie, Duluth, Askov, and Hillman.

STANDARDIZATION OF CERTAIN PRACTICES IN STONE HAULING

Stone Transportation

Clearing land of stone is a relatively simple operation. Assuming that the stones are small enough to be handled readily by one or two men, it consists essentially in loading them on a means of transportation and hauling them away. The problems of getting the stones to the surface of the ground and of breaking the larger boulders will be taken up later.

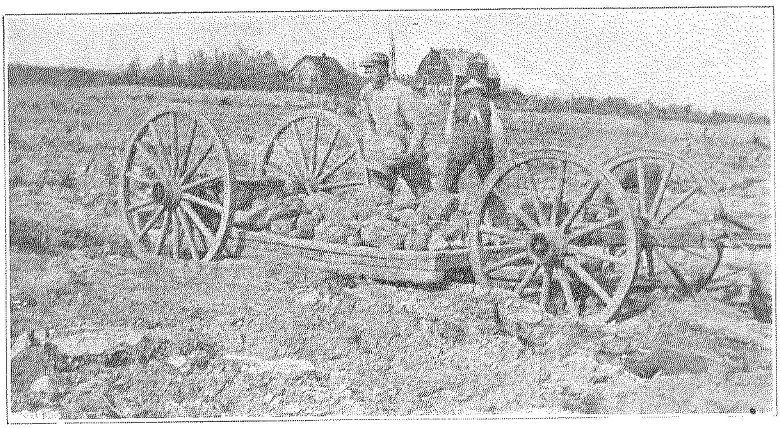

Fig. 1. A wagon with a low bed may be loaded as easily as the stone boat, yet the load is on wheels instead of on runners.

Wagons.—Vehicles in common use for hauling field stones may be divided into two general classes: Those on wheels, and those on runners. Obviously the first type is better suited for long distance hauling as well as for hauling large loads. The studies included the use of three types of wagons—the ordinary farm wagon with a plank bed, a special low wagon (Fig. 1), and a dump wagon (Fig. 2).

One important difference between the various means of hauling is the height to which it is necessary to lift the stones. In general, the advantage in this respect is in favor of stone boats. A farm wagon, if used for this purpose, should be as low as possible. A bed of 3-inch plank 12 feet long with side planks 10 or 12 inches wide is satisfactory. It will hold a load as heavy as can be hauled by an ordinary team. It has the disadvantage that all the stones must be lifted high to be loaded.

If the stones are not too large, the load may be dumped while starting a pile, but if the stones are to be stacked rather than spread out in a broad, flat pile, other methods must be resorted to. Large stones must be thrown off or, if they are too large for this, they may be unloaded as shown in Figure 3, using one of the side planks from the wagon.

A special low wagon is shown in Figure 1. This can easily be made with the help of a blacksmith by using the trucks from an ordinary farm wagon and attaching a well-made bed underneath the axles. The

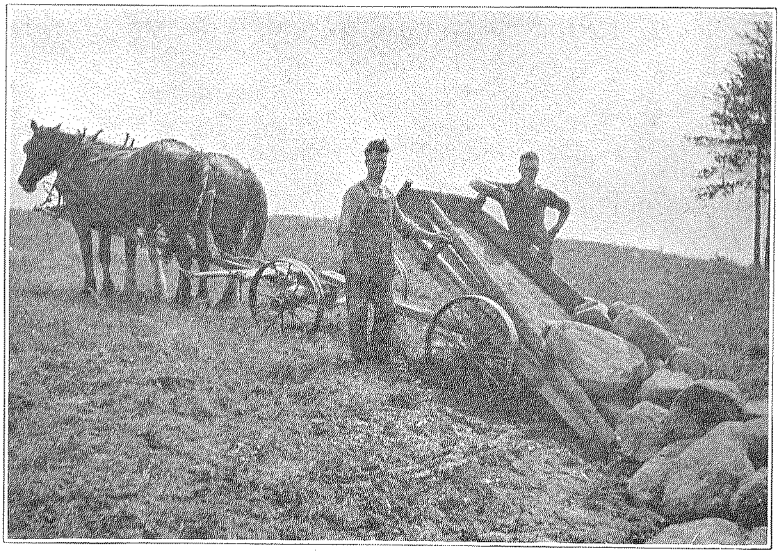

Fig. 2. This type of wagon may be unloaded easily and quickly if the stones can be dumped into a ravine or an excavation.

front of the platform must be pointed and be far enough back to allow for turning. The principal advantage of this type of wagon is that it is easily loaded and at the same time the load is on wheels rather than on sleds. It is impossible to haul as large a load as with the farm wagon and unloading is somewhat more difficult.

A third type of wagon tested is the dump wagon (Fig. 2). The body is hinged above the rear axle with the center of gravity slightly in front of the axle. The outstanding feature is that it may be unloaded quickly by tipping up the front of the body. Sometimes part of the load must be moved from the front to the rear before this can be done. The tipping feature is especially advantageous when unloading stones into an excavation or a natural ravine. It is impossible to haul as heavy a load on a wagon of this kind as on a regular farm wagon. As practically the entire load is on the rear axle, the draft is unusually heavy.

Sleds.—The most common sled is the ordinary stone boat, found on almost every farm. Stone boats are made in various sizes and styles, and should be well built. Where a tractor is used for power, a piece of boiler plate about 1/4 inch thick and of suitable length and breadth is sometimes used. Usually, however, stone boats are made of wood. One made of 3-inch plank with a cast iron nose, about 3 1/2 feet wide and 6 or 7 feet long, is satisfactory. On each side is a rail—a piece 4x4 inches or its equivalent, bolted firmly to the base. A stone boat this size will hold all that can be hauled by a team.

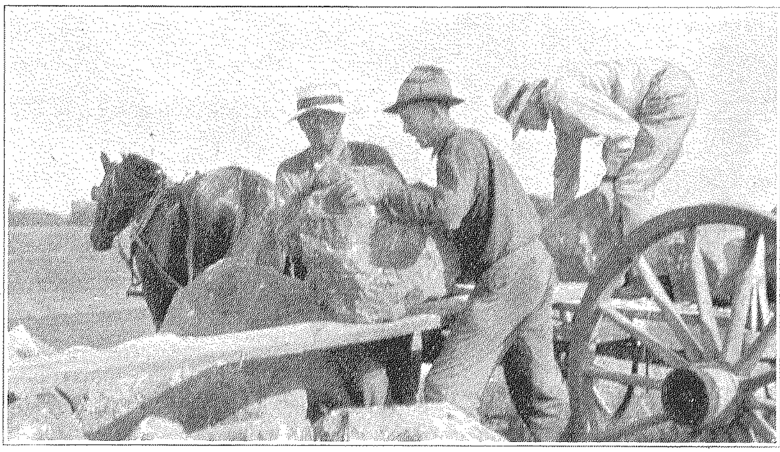

Fig. 3. Large boulders may be rolled from the wagon on a plank to get them on top of the pile, thus making possible a higher and more compact pile.

This vehicle is relatively easy to load. The loads must be much smaller, however, than wagon loads; and much more energy is required to move a given mass of stone a given distance.

Comparison of Four Means of Transportation When the Hauling Distance Is Short and Constant

The data presented here are applicable only for stones that can be handled by two or three men. This includes the field stones ordinarily encountered, but does not include boulders so large that they could not be loaded on a wagon or stone boat by two or three men. The large boulders present another problem. On cleared land they are usually handled individually. Various ways of handling them are discussed on pages 13 to 21.

It is difficult to compare vehicles because several factors must be considered and these may change conditions. The distance to which stones are hauled is one of the most important factors.

Table I and Figure 4 show a comparison of four vehicles for a hauling distance of 200 feet. The figures in the table are averages of three series of tests, two of which were conducted at Askov, Pine County, and one near Guthrie, Hubbard County. At each place the crew consisted of two men and one team for each vehicle.

TABLE I

Comparison of Various Means of Transporting Stones, in Cubic Feet per Hour, on Sod Land and on Broken Land, Where Hauling Distance Is 200 Feet

Vehicle	Cubic feet of stone per hour	
	On sod land	On broken land
Dump wagon	115.2	83.5
Low wagon	100.0	77.5
Farm wagon	96.6	76.2
Stone boat	68.8	53.3

Each vehicle was used on sod land and on broken land. All plots cleared were virgin land from which the brush and stumps had been removed. The first operation of stoning consisted in prying out the

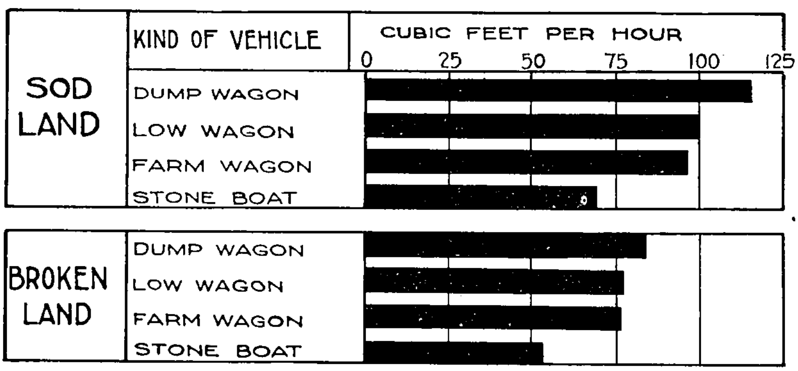

Fig. 4. Comparison of various means of hauling stones a distance of 200 feet.

stones that were partly buried but were visible. This was done so that a thoro job of removing stones from the surface might be accomplished before the breaking was done. After the ground was broken there was a second crop of stones. This was usually not so large as the first crop but was more difficult to move because of the plowed ground.

This accounts for the fact that the volume of stone per hour for each vehicle is about 20 per cent less on broken land than on sod land. The difference is slightly greater with wheeled vehicles than with the stone boat and is greatest with the dump wagon, because the dump wagon pulls heavier than the other two types and plowed ground offers additional resistance.

Both special wagons give slightly more volume per unit of time than the ordinary farm wagon, because the dump wagon is easier to unload and the low wagon is easier to load than the other two. Whether or not either of the special wagons is to be used depends on the amount of stone hauling to be done. Another consideration is the cost and the possibility of using it to advantage for some other purpose. The cost will depend on what equipment is available. If trucks are available the cost should be relatively small.

While the stone boat apparently is at a distinct disadvantage as compared with the other three, under certain conditions its use is justified. Many stones are so large that they can not easily be loaded on a wagon but may be rolled on the stone boat. Again, one man working alone can handle relatively larger stones with a stone boat than with a wagon. Rough ground, a short haul, or a peculiar unloading situation may make the stone boat more desirable.

Comparison of Different Means of Transportation at Varying Distances

The stone boat and the farm wagon were the only vehicles used in this experiment. Figure 5 shows the relationship between the two on sod land and on broken land—the same general relationship as in the previous experiment. After ground is broken, stone removal takes more time and is more expensive. That is one reason why it seems to be better practice to make the job as thoro as possible before any breaking is done.

The curves in Figure 5 indicate that with a short haul the stone boat approaches the wagon in economy. As the haul becomes longer, the lines spread, showing that the wagon is relatively more efficient.

While the efficiency of both vehicles decreases as distance increases, efficiency of the stone boat decreases no faster during the last several hundred feet of haul than that of the wagon.

The figures for several experiments were averaged and are presented in Figure 5. While each experiment involved the clearing of from one to two acres, the time consumed on each plot was relatively short. It is believed that the stone boat loads, in general, were harder to pull than wagon loads, and therefore the horses were actually working harder with the stone boat. It would be difficult to determine the difference.

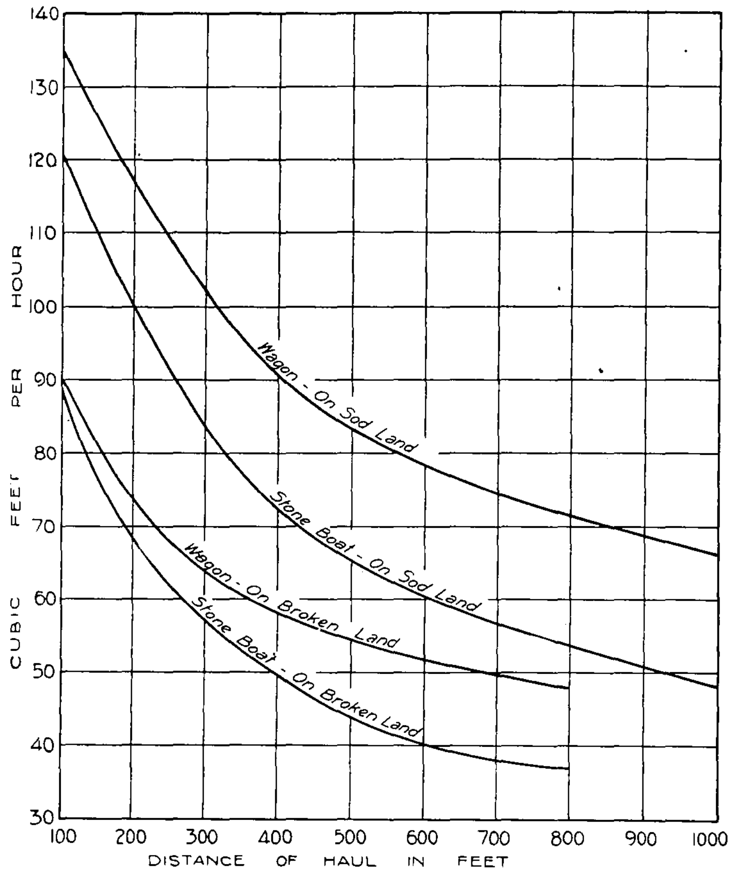

Fig. 5. Comparison of wagon and stone boat at varying distances on sod land and on broken land.

It does not appear in data covering relatively short experiments but would in data covering a longer time. After several days of work on a stone boat, the team would move slower and would have to be rested oftener or the loads would have to be made lighter.

It is self-evident that more power is required to move a given load on sleds than on wheels. As the distance increases, it becomes increasingly more important to have the load on wheels. If the distance is very short, this disadvantage tends to be overcome by the fact that the stone boat is easier to load; but as the hauling distance becomes greater the importance of difference in loading becomes relatively less significant.

Standard size of load.—How is the size of a load of stone measured? Two possibilities present themselves—by weight and by volume. Each appears to have both advantages and disadvantages.

The weight of a cubic foot of field stones as commonly piled is about 100 pounds. A load of field stones of various shapes and sizes will not always weigh the same per unit volume. One combination of sizes will allow more air space than another, hence will weigh less per cubic foot. For these reasons a clearer idea of the quantity of stone in question could be obtained in terms of weight than in terms of volume. In actual practice, however, the weight designation is less practical than the volume. It would be expensive and would take considerable time to weigh loads of stone and facilities are seldom available.

For practical purposes, the volume method seems best. Stones and stone materials are usually so measured. Volume can not always be determined accurately. This is especially true when the stones are put in odd-shaped piles or are scattered over the ground.

In comparing methods of transportation, however, the cubic foot as a unit of measure will be used throughout the discussions.

Table II gives the number of cubic feet of stone hauled by each of the vehicles used. The figures are averages of many loads. They represent about what may be expected with each type of vehicle under average conditions. The weights were calculated from the volume, the stones were not weighed.

TABLE II

Average Volume and Weight of Field Stones Required to Make a Load for Each of Four Types of Vehicles

Vehicle	Cubic feet	Pounds
Farm wagon	28	2,800
Dump wagon	20	2,000
Low wagon	19	1,900
Stone boat	10	1,000

Time required for loading.—The time required to put on a load of field stones will vary considerably, depending on several factors, the most important of which is the number of stones per square rod or per acre. If the stones are so numerous that a wagon load may be picked up without moving the wagon, much less time will be required than if they are scattered.

Another important factor is the size of stones. Best headway can be made with the largest stones that can be loaded by two men. Not many such stones are required to make a load. If they are larger than this and if an attempt is made to load them without breaking, considerable time will be wasted in devising ways and means of lifting them. On the other hand, if the stones are relatively small, it is necessary to handle a large number. This takes considerable time.

Two men working together can usually accomplish more than twice as much as one man working alone.

A stone carrier may be used for the larger stones. This is made of two pieces of one-inch gas pipe or wooden pieces of equal strength about

3½ feet long, placed about 18 inches apart and connected with a network of wire (Fig. 6). The advantage in its use is that it provides a handhold on the stones. Many stones are round and, while two men could lift them they could not hold them.

Records kept on a large number of loads under varying conditions show that the average time required to load a wagon is about 27 man minutes, and to load a stone boat about 16 man minutes, with two men

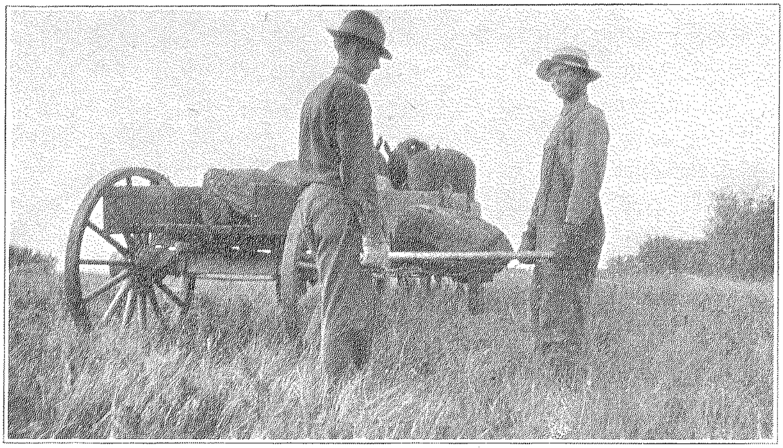

Fig. 6. A stone carrier enables two men to load comparatively large stones rapidly.

working together. On sod land where there is fairly good footing and where the stones are concentrated, about 13½ minutes for a wagon load and 8 minutes for a stone boat load, are required for the first picking. On broken land, more time is required because the ground is rougher and the stones are usually farther apart than at the first picking.

The picture on the cover page gives an idea of the stone density where these data were obtained. This picture was taken after the stones had been raised to the surface by crowbars preparatory to the first picking.

Time required for unloading.—This part of the stoning operation frequently requires as much time as loading. The method depends on how the stones are disposed of and the kind of vehicle used. When using a wagon with a plank bed, the load may be dumped if the stones are not too large and while the pile is still small.

As a rule it is difficult to build a stone pile very high. The natural tendency is to spread it over a large area. Unloading large stones from a wagon is sometimes facilitated by rolling them along a plank from the wagon to the center of the pile (Fig. 3). Small stones may be unloaded with a potato fork (Fig. 7).

The stone boat is advantageous in loading large stones but is disadvantageous in unloading, especially if the stones are to be piled.

If stones may be disposed of in a natural ravine or gully or if they may be dropped into a trench, unloading is simplified. Advantage may then be taken of the dump wagon illustrated in Figure 2.

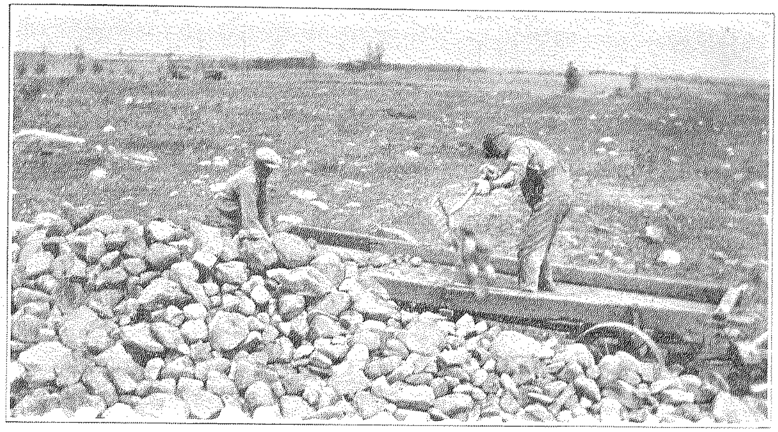

Fig. 7. The use of a potato fork facilitates the unloading of small stones.

While the stone pile is small, from 3 to 5 minutes will be required for two men to unload a stone boat and from 6 to 8 minutes to unload a wagon. As unloading becomes more difficult, the time increases to 10 or 12 minutes for a stone boat and 15 or 20 minutes for a wagon.

A dump wagon can be unloaded in one or 2 minutes. If a considerable quantity of stone is to be removed, a dump wagon will save time and labor.

CLEARING LAND OF LARGE BOULDERS

Rock Blasting

As was indicated previously, large boulders present a special problem. On land that is not too stony to clear, large stones requiring special attention are usually scattered. Clearing is largely a matter of handling each stone singly rather than in a group as with smaller field stones.

Explosives may frequently be used to advantage. The most economical use of explosives requires a thoro understanding of the different methods of blasting and of what may be accomplished by each method.[2]

Mud-capping.—One method of blasting is commonly known as "mud-capping." The object is to break the stone. It consists in placing the explosive on the surface of the stone in a compact heap and

[2] The details of handling explosives are given in Minnesota Special Bulletin No. 110, The Use of Explosives on the Farm, by A. J. Schwantes. 1926.

covering it with 10 or 12 inches of stiff mud. To obtain best results this covering of mud must be large and wet. Mud is cheaper than explosives, and a small covering of comparatively dry dirt will waste explosive force. The mud should be free from stones, sod, leaves, twigs, and other foreign material. If the stone to be broken tends to be flat rather than round, the charge should be placed on a flat side, not at one end. A natural crevice or depression is an ideal location for the charge.

If more than two or three sticks of explosives are used in one load, it is usually best to pour the powder out of the paper wrapper. This makes it possible to get all the powder in a small compact heap, with a minimum of air space, which can not be done when the sticks are placed on the stone. The heap of explosive should be covered with one or more of the wrappers that were around the sticks, to keep out moisture. A blasting cap with fuse attached or an electric cap is put into the powder before the mud is put over it.

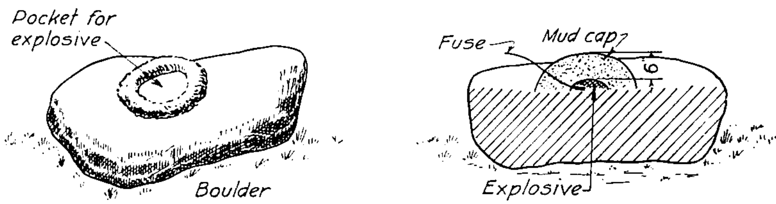

Fig. 8. To make a good mud-cap, use a thick covering of stiff mud

If the charge is large enough and the mud-capping has been properly done, the force of the explosion will break the stone. To do the work most satisfactorily and efficiently, a quick-acting explosive is necessary. Fifty or 60 per cent dynamite is much better than 20 or 30 per cent. The stone to be broken should always be entirely exposed. When part or all of the stone is buried, either of two methods may be used: (1) A narrow trench may be dug around the stone down to the bottom of it. This will give it room to expand when the charge is exploded, and consequently will make it much easier to break; or (2) a charge of explosive may be placed under the stone to throw it out of the ground preparatory to mud-capping.

Underdrilling.—This method of blasting consists in making a hole in the ground underneath the rock with an auger or a driving iron. The charge is placed much as it would be under a stump (see Fig. 9). A low-grade explosive, 20 or 30 per cent, is suitable for this purpose. The charge is usually so located that there is a quantity of dirt between it and the under side of the stone. This acts as a cushion to break the force of the explosion, consequently stones blasted by this method are thrown out of the ground if a large enough charge is used, but are seldom broken.

Undermining.—This method is illustrated in Figure 10. The object in placing the charge as shown is to break the stone with the same charge that is used to throw it out. It is practically the same thing as putting a mud-cap underneath. Because the stone is to be broken, it is well to use a quick-acting explosive—from 40 to 60 per cent. Special attention must be paid to getting the charge close against the lower side of the stone with no dirt or other foreign material between the two. To make this possible, it is sometimes necessary to dig down on one side slightly below the bottom of the stone and make a small

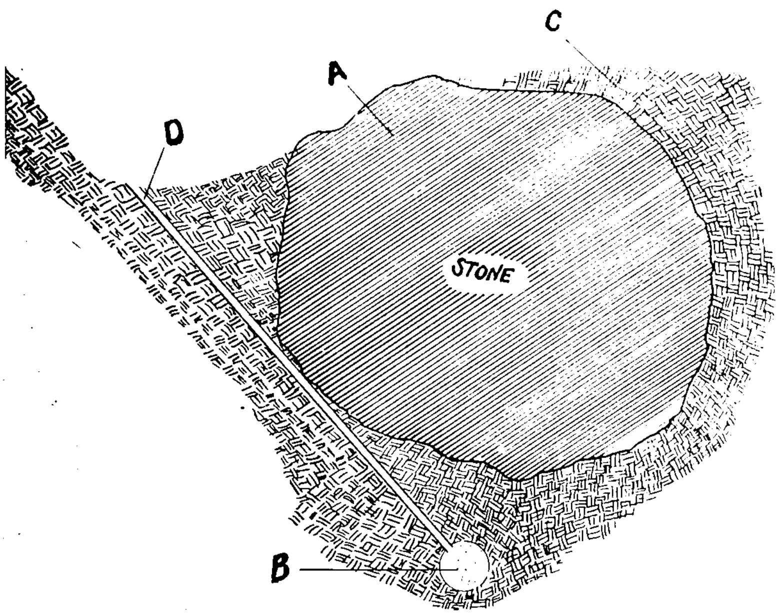

Fig. 9. Underdrilling to place the explosive under the stone.

A. Stone
B. Pocket large enough for necessary explosives
C. Soil
D. Hole made with driving iron or dirt augur

cavity underneath in which to place the charge "E" as shown in Figure 10. The explosive should be placed as nearly as possible under the center. If the stone is partly or entirely buried, something of its size and shape may be learned by probing around it with a bar.

When stones are almost or entirely buried, it is usually more economical to use the undermining method than to use a combination of the other two. Some additional labor is required to place the charge, but this is usually more than repaid by the saving in cost of explosive.

If only a small portion of the stone is beneath the surface of the ground, it may be more economical to dig a narrow trench around it before mud-capping.

Drilling.—Still another method is drilling into the rock. Explosives are most effective when confined in a drill hole. The method is used very little in land clearing, however, because the cost of drilling usually amounts to more than the saving in explosives.

Relative Cost of Various Methods of Handling Large Boulders

Several possibilities are open in getting rid of boulders. Explosives may be used in various ways, but some methods do not involve the use of explosives, and others call for their use in only a secondary manner.

Burying boulders without breaking them.—This method consists essentially in digging a hole in the ground immediately adjoining and perhaps slightly underneath one edge of the boulder to be buried. The

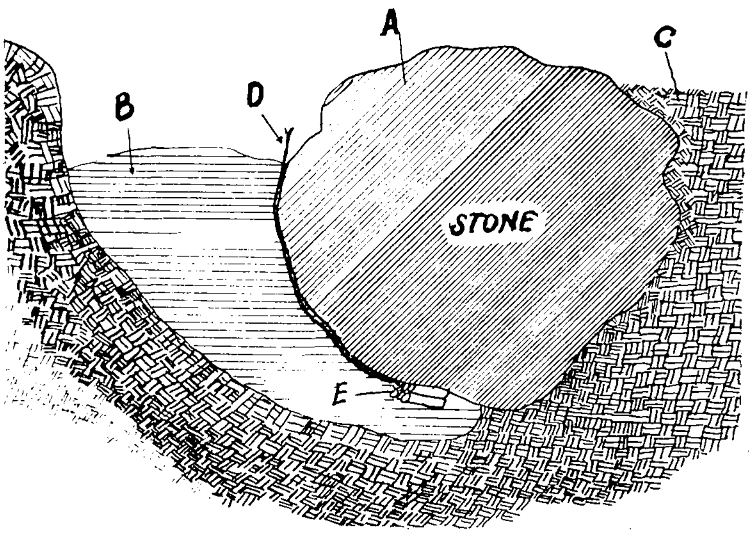

Fig. 10. Undermining to break the stone and throw it out.

A. Stone
B. Soil shoveled in after charge has been placed
C. Soil
D. Fuse
E. Explosive charge

excavation must be large enough to hold the boulder and deep enough that it can be covered with a foot or more of earth.

Table III gives the result of trials of this method; Part A gives results obtained where most of the work was done by man labor. A small amount of horse labor was used in two instances to help cover the stone after it had been dropped into the hole. Part B shows the results obtained when explosives were used. In each case, costs were figured per cubic foot of stone so that a fair comparison of the different methods might be made.

TABLE III

COST OF BURYING BOULDERS WITHOUT BREAKING THEM

A—BY HAND WORK ENTIRELY

Stone No.	Volume of stone	Time required: Man hours	Time required: Horse hours	Total cost*	Cost per cubic foot of stone
	cu. ft.				
1	77	3.5		$1.05	$0.014
2	62	2.8		0.84	0.014
3	50	2.7		0.81	0.016
4	30	2.1		0.63	0.021
5	24	3.2	0.50	1.03	0.043
6	22	4.9	0.67	1.57	0.071
7	16	1.8		0.54	0.034
Av.	40	3.0	0.59	$0.92	$0.030

* Man labor was figured at 30 cents per hour and horse labor at 15 cents per hour.

B—BY BURYING WITH EXPLOSIVES

Stone No.	Volume of stone	Time required man hours	Explosive materials used: Dynamite sticks	Caps	Fuse	Cost*: Labor	Explosive materials	Total	Per cubic foot of stone
	cu. ft.				ft.				
1	50.0	1.3	7	3	3.0	$0.39	$0.64	$1.03	$0.021
2	47.3	2.3	9	1	3.5	0.69	0.77	1.46	0.031
3	45.0	1.9	11	2	2.5	0.57	0.94	1.51	0.033
4	35.5	1.5	10	4	3.0	0.45	0.89	1.34	0.038
5	28.0	1.2	12	2	3.5	0.36	1.03	1.39	0.050†
6	21.5	2.0	9	2	4.0	0.60	0.79	1.39	0.064†
Av.	37.8	1.7	9.6	2.3	3.25	0.51	0.84	1.35	0.039

* The cost of labor and materials was figured on the following basis: Man labor 30 cents per hour, dynamite 8 cents per stick, blasting caps 1½ cents each, and fuse 1 cent per foot.

† The relatively high cost per unit volume is due to the fact that they were in heavy soil, thus requiring more labor and more explosive materials.

It will be noted that the average cost is somewhat higher with the aid of explosives than with man labor only. When explosives are used the time consumed per stone is 1.7 hours as compared with 3 hours without the aid of explosives.

There is a wide range in the cost of burying individual stones. There seems to be no relation between this cost and the size of the stones. To a large extent this difference in cost is due to differences in soil. The trials recorded in Table III, A and B, were conducted on soil types representing easy and hard digging. Explosives are more advantageous in hard than in loose soils.

The burying of large boulders is a dangerous occupation. The natural tendency is for the workman to get the excavation as far under the stone as possible, so that the stone may be rolled in easily. If too much dirt is removed from beneath the stone it is likely to fall too soon and thus endanger the man who is working in the hole.

It is not good practice to leave a job of this kind unfinished in the evening, especially if it is likely to rain during the night. The principal danger is that the stone is likely to wash into the hole when it is only partly large enough, in which case an entirely new excavation must be made.

Breaking boulders with explosives and removing them.—This method has been discussed on pages 13 to 16, but is mentioned here by way of a comparison with burying. Table IV gives costs of removing boulders by breaking—more than 4 cents per cubic foot. It is higher than by either of the other methods discussed. This cost, however, includes removing from the ground, breaking, hauling the pieces off the field, and filling the hole left in the ground. The total time consumed per stone is 1.6 hours—about the same as the time required for burying with the aid of explosives. Obviously, the one advantage of this method is that the stone is definitely removed from the field. If the stone can be used for building or other purposes, this method has another advantage.

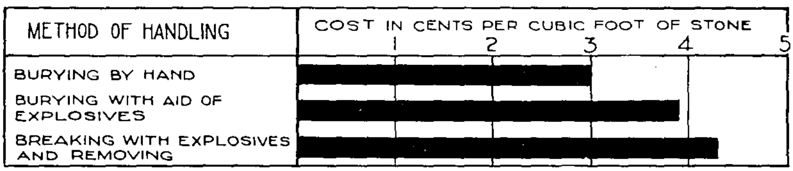

Fig. 11. Relative cost of various methods of handling large boulders.

Exclusive use of mechanical means for removing boulders.—Several mechanical devices have been used in handling large stones. As a rule they are designed especially for this purpose and can not well be used for any other. No data will be presented here concerning the cost of using such means, because it is believed that in general their use is expensive—not because of the possible inefficiency of the outfit, but because a farmer would have little use for it and the overhead cost would be high. In general, it is thought that one of the methods described is better.

What is the necessary size of charge to break boulders by the mud-cap method?—The process of mud-capping was described on pages 13 and 14. Before we can intelligently discuss the size of charge required to break stones by this method we must consider the factors that influence it.

Stones vary in kind and in size. Some are brittle while others are relatively soft. In general, however, from a land clearing standpoint, the field stones found in Minnesota do not vary much. They are largely granitic. The slight variations have no appreciable influence on the force required to break them.

TABLE IV

COST OF BREAKING BOULDERS WITH EXPLOSIVES AND REMOVING THEM

Stone No.	Volume of stone, cu. ft.	Method of blasting used	Time required		Explosive materials used			Cost*			
			Man hours	Horse hours	Dynamite sticks	Caps	Fuse, feet	Labor	Explosive materials	Total	Per cubic foot of stone
1	100.0	Underdrill and mud cap	4.5	2.5	32	2	4.0	$1.73	$2.63	$4.36	$0.044
2	69.5	do	1.3	0.7	19	3	3.0	0.50	1.60	2.10	0.032
3	36.0	do	1.3	0.8	10	2	2.0	0.51	0.85	1.36	0.038
4	30.0	Undermine	1.3	0.8	6	1	3.0	0.51	0.52	1.03	0.034
5	27.0	Underdrill and mud cap	1.2	0.7	8	2	2.0	0.47	0.69	1.16	0.043
6	25.3	do	1.3	0.8	10	3	2.5	0.51	0.87	1.38	0.054
7	22.5	do	0.9	0.5	11	2	2.0	0.35	0.93	1.28	0.057
8	21.0	Undermine	1.0	0.7	5	1	1.5	0.40	0.43	0.83	0.039
Av.	41.4		1.6	0.94	12.6	2	2.5	$0.63	$1.07	$1.69	$0.043

* The cost of labor and materials was figured on the following basis: Man labor 30 cents per hour, horse labor 15 cents per hour, dynamite 8 cents per stick, blasting caps 1½ cents each, and fuse 1 cent per foot.

Because stones are found in all shapes as well as all sizes, two factors must be considered in this respect—the volume of the stone and the diameter perpendicular to the position of the charge.

To determine how much each of these factors influences the size of charge, 200 stones were blasted, 100 with 40 per cent and 100 with 60 per cent dynamite. Accurate measurements were made of each stone before it was blasted. The diameter perpendicular to the position of the charge was determined as well as three circumference measurements. These circumference measurements were used to determine the volume.[3]

All the stones were entirely out of the ground when the blasting was done. The mud caps were all made of the same material and were of about the same consistency, and the blasting was done by the same two men, who had had considerable experience in work of this kind.

The charge was estimated for each stone. After each blast a corrected charge was arrived at, based on the work done by the charge used. The objective that was kept in mind was to break the stone into small enough pieces that one man could handle them, but not much smaller.

The field work furnished data of 100 stones blasted with 40 per cent dynamite, giving the volume of each stone, the diameter perpendicular to the charge, and the size of charge necessary to break it. Similar data were also recorded for 60 per cent dynamite.

Using the "Pearsonian method" of correlation, the size of charge was correlated with volume and also with diameter in each case. Table V summarizes the results of these correlations.

TABLE V

COEFFICIENTS OF CORRELATION BETWEEN SIZE OF CHARGE AND VOLUME OF STONE, AND SIZE OF CHARGE AND DIAMETER OF STONE FOR BOTH 40 PER CENT AND 60 PER CENT DYNAMITE

Kind of dynamite	Coefficients between size of charge and volume	Coefficients between size of charge and diameter
40 per cent	0.927	0.878
60 per cent	0.924	0.848

A perfect positive correlation would give a coefficient of 1, and where there is no correlation whatever, the coefficient would be 0. There is a relatively high coefficient of correlation in each case, which indicates that both volume and diameter have a very distinct influence on size of charge. It will be noted further that in both cases the correlation between volume and size of charge is much higher than be-

[3] For determining the volume, the stones were divided into three classes: (1) Those most nearly resembling a sphere, (2) those most nearly resembling an oblate spheroid, and (3) those most nearly resembling a prolate spheroid. The respective formula for volume was then used on each group.

tween diameter and size of charge. The conclusion that may be drawn from this is that while the diameter perpendicular to the charge is of considerable importance in determining the size of the charge, the volume bears a closer relationship and therefore is of more importance. If it were necessary to use only one factor, volume is the most significant.

On the basis of the data obtained, a formula[4] has been worked out for determining the size of charge. This formula takes into account both the volume and the diameter and will give a close estimate of the proper size of charge for stones with a volume up to about 25 cubic feet. For larger stones the formula will give a result slightly larger than is required. This is because the efficiency of explosives tends to be greater (within practical limits) on larger stones than on smaller ones.

If 40 per cent dynamite is used, the following formula may be used: $S = \frac{V}{4} + \frac{D}{16} - \frac{1}{4}$; for 60 per cent dynamite, $S = \frac{V}{4} + \frac{D}{40}$ will be applicable. S = size of charge in sticks; V = volume of stone in cubic feet; D = diameter of stone perpendicular to location of charge, in inches. These formulas may also be used as a guide in determining the proper size of charge to use for undermining, described on page 15.

It is found that a very definite relationship exists between the amount of 60 per cent dynamite required and the amount of 40 per cent. About one pound of 40 per cent dynamite will do the same work as 0.8 pound of 60 per cent. This means that paying 25 per cent more for 60 per cent dynamite than for 40 per cent is justified.

STONE DISPOSITION

The stone pile or several piles placed at random in a cultivated field are familiar scenes. Because of the weight of the stones it is difficult to pile them very high and they often not only cover a great deal of ground but are unsightly and cause great inconvenience when the field is cultivated. Around these piles, brush and weeds soon grow up and are an excellent harbor for rodents. The unfortunate thing about a stone pile is that it will never burn or rot.

Some prefer to bury stones for the sake of getting them out of the way. This practice, while followed by some, is opposed by others be-

[4] The following equations were arrived at: For 40 per cent dynamite $S = 0.268V + 0.057D - 0.265$; for 60 per cent dynamite $S = 0.222V + 0.036D - 0.02$. Putting these in simpler form so that they may be more readily applied:

For 40 per cent dynamite $S = \frac{V}{4} + \frac{D}{16} - \frac{1}{4}$; for 60 per cent dynamite $S = \frac{V}{4} + \frac{D}{40}$.

cause they believe that stones will come back to the surface in the course of time. Stones have been known gradually to come to the surface in cultivated fields, but there seems to be some disagreement as to whether the stones rise or whether the surface becomes lower. It is likely that they do actually rise when they are partly on the surface or near enough to the surface that frost affects the largest part of the stone. On the other hand, some of our soils are gradually but constantly wearing down because of the action of wind, water, and frost, and it seems reasonable that to some extent this would bring stones nearer the surface.

A study was started recently at three different points in Minnesota for the purpose of throwing some light on this question. Stones were buried at various depths ranging from 7 feet to ½ foot and at intervals of 6 inches. A pipe set on the top of each stone and extending to the surface provides a means for reaching the stone with a level rod. Readings are made of the elevations of these stones each spring and each fall and careful records are kept of factors that might influence the elevation—depth of frost, moisture content, and kind of soil. An attempt is made at the same time to determine whether the surface of the soil is wearing down.

The practice of burying large boulders individually has already been discussed, and costs are given in Table III. The regular run of field stones may be buried in trenches or pits dug for that purpose. These should be located in a hollow, if possible, rather than on the side or the top of a hill. Explosives are frequently used for making such excavations. Much better results will be obtained from explosives in moist soil than in dry soil.

One method that gives good results consists in loading a charge of about 50 pounds of dynamite about 10 feet deep in the ground. Two men and a team will scrape out most of the loose dirt left in the hole after the blast in four or five hours. This will hold about 10 cords of stone filled to within 18 inches of the top and the cost of burying is somewhat less than $2.00 a cord. This does not include the cost of hauling the stones.

Another method is to make trenches. These may be any desired length but usually are not made as deep as a pit. The cost per cord when burying in trenches is somewhat higher, ranging from $2.00 to $4.00. A deep excavation is more efficient because it provides more space per unit of surface dirt removed, which must be returned to cover the stones.

Field stones can frequently be used about the farm for foundation work and also in concrete work. Whether or not it would pay to put in equipment and crush them to replace gravel depends on the possibility of obtaining supplies of gravel for road making or for other purposes, and also on the cost of such gravel, if obtainable.

Stone fences, while not common, are sometimes built. They have the disadvantage of encouraging the growth of weeds and brush around them and of becoming a harbor for rodents, but they are permanent and are neat if properly built.

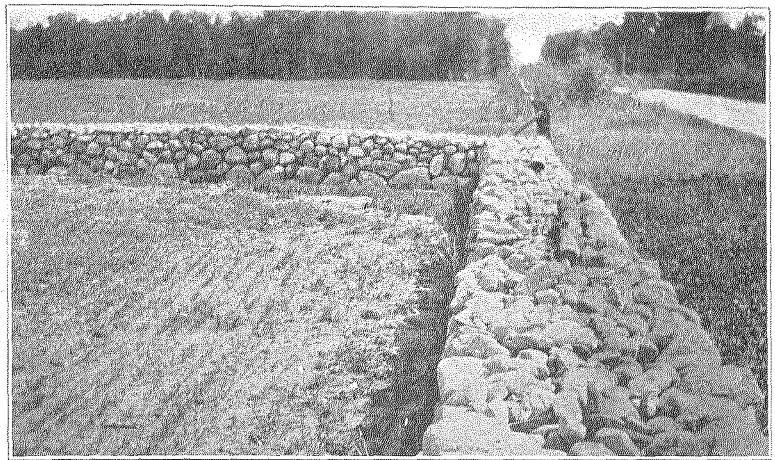

Fig. 12. A well built stone fence is serviceable and neat.

If there is no immediate use for stones at time of clearing, the matter of their disposal should be considered. A stone pile may be so located as to be a permanent inconvenience when with a little planning these stones might have been put where they would serve some useful purpose or at least be out of the way.

AN ANALYSIS OF STONE REMOVAL COSTS

Stone removal is different from stump removal. The latter is accomplished by going over the ground once. Clearing a field of stones usually goes on for years. All the stones can not be removed the first time over because many are partly or entirely buried and yet are close enough to the surface to be within reach of the plow.

It is not necessary to remove all the stones before land can be cropped, but it is desirable to have the fields as free from stones as possible to facilitate seedbed preparation, planting, and harvesting.

On land that has never been broken, some extra effort may be expended to get all the stones out as soon as possible. With this objective the procedure would be about as follows:

All stones partly below the surface are brought to the surface by means of crowbars. The amount of time required to do this will vary with the amount of stone. On the experimental plots, from 2.8 to 16.5 man hours were required per acre, an average of 8.1 man hours.

Two men can work to good advantage at this job. Sometimes a stone that is difficult for one man to get out or that would take a considerable amount of his time can be gotten out very easily by two men. One man should have a bar at least 8 feet long with which to pry.

All this is done before picking is begun. The field now looks as in the picture on the cover. After the first crop of stones has been removed, the land is broken. It is a good plan for one or two men to follow the breaking plow and throw out stones that have been loosened by the plow to prevent their being covered again by the next furrow. If there are large stones in the field that require blasting, mark their location. These are found either by the breaking crew or by the men who keep the furrow free from loose stones.

After breaking, the second crop is removed and after the ground has been disked once or twice a third crop may be gathered. If all the work up to this stage has been done thoroly, the largest volume of stones will have been removed before the first crop is put in. It will be necessary to remove stones after successive plowings for several years, but the amount will be relatively small and there will be little interference with the operation of tillage machinery.

In contrast with this method of removing the stones as thoroly as possible the first few times over, many farmers remove from time to time only those that appear on the surface during the course of cultivation, after they become a real hindrance to soil tillage.

The latter method obviously has the advantage of requiring less labor at the time of the first clearing and before the first crop is planted. If the amount of labor is a limiting factor, this may help to get a first crop on a larger area than if the job is done thoroly. On the other hand, the job is prolonged several years and in the meantime farming operations must be carried on. This is hard on machinery, makes tillage operations slower, and makes the work more disagreeable. Perhaps the yields on stony land would be lower than on land that had been more thoroly cleared.

To determine which of these methods is best under average conditions is the object of an experiment in progress at the time of this writing. Results seem to indicate that it is better business to remove the stones as thoroly as possible the first time over. More definite information will be available in about two years.

TABLE VI

UNITS OF LABOR AND MATERIAL REQUIRED FOR CLEARING LAND OF STONES WITH A HAULING DISTANCE OF 200 FEET

Plot No.	Prying		Hauling				Blasting				Total			
	Per acre	Per cord	Per acre		Per cord		Per acre				Per acre		Per cord	
	Man hours	Man hours	Man hours	Horse hours	Man hours	Horse hours	Man hours	Dynamite sticks	Caps	Fuse, feet	Man hours	Horse hours	Man hours	Horse hours
1..........	12.0	0.76	53.5	47.2	3.4	3.1	2.0	36	20	30	67.5	47.2	4.3	3.1
2..........	16.5	0.99	49.5	48.2	3.0	2.9	1.0	16	4	4	67.0	48.2	4.0	2.9
3..........	12.0	0.92	49.2	41.6	3.8	3.2	1.5	24	20	30	62.7	41.6	4.8	3.2
4..........	6.5	0.40	49.2	43.2	3.0	2.7	4.0	72	20	20	59.7	43.2	3.6	2.7
5..........	14.5	1.05	43.6	43.6	3.2	3.2	1.5	18	10	30	59.6	43.6	4.4	3.2
6..........	2.8	0.20	42.0	32.2	2.9	2.3	2.0	46	16	20	46.8	32.2	3.2	2.3
7..........	3.8	0.45	39.8	33.2	4.7	3.9	0.8	14	4	4	44.4	33.2	5.2	3.9
8..........	5.2	0.62	24.0	24.0	2.9	2.9	2.0	41	18	30	31.2	24.0	3.7	2.9
9..........	3.8	0.62	26.4	22.2	4.3	3.6	0.8	14	4	4	31.0	22.2	5.1	3.6
10..........	3.8	1.47	25.4	13.0	6.6	3.4	0.8	14	4	4	30.0	13.0	8.3	3.4
Av..........	8.1	0.75	40.2	34.8	3.8	3.1	1.7	30	13	18	50.0	34.8	4.7	3.1

Table VI gives a summary of stone removal requirements, expressed in terms of labor and material units. Actual costs are given in Table VII. These figures represent only the clearing before breaking and the first picking after breaking—they do not represent the total cost. The work was done thoroly, however, hence not much stone remained. The cost per acre depends on the number of stones and the distance they are hauled. It seems, therefore, that the better cost unit is the cord.

Hauling is by far the largest item of cost—75 per cent of the total. The hauling distance in all cases shown in the table was relatively short, in no instance being much more than 200 feet. If the distance is increased, the total cost per acre and also per cord will be increased in proportion and the other factors of cost become relatively less important.

TABLE VII

SUMMARY OF STONE REMOVAL COSTS WITH A HAULING DISTANCE OF 200 FEET*

	Man labor	Horse labor	Materials	Total
Per acre	$15.00	$5.22	$2.78	$23.00
Per cord	$ 1.41	$0.47	$0.24	$ 2.12
Per cent of total cost	65.2	22.7	12.1	100.0

* These figures are based on a cost of 30 cents per hour for man labor, 15 cents per hour for horse labor, 8 cents per stick for dynamite, 1½ cents each for blasting caps, and 1 cent per foot for fuse.

The relation between cost and hauling distance is indicated in Figure 5. The cost per cord does not vary directly as the distance. With the farm wagon, for instance, on sod land, about 135 cubic feet (almost 7 tons) can be hauled per hour to a distance of 100 feet. At 500 feet this drops to 83 cubic feet (about 4 tons), and at a distance of 1,000 feet, 66 cubic feet (slightly more than 3 tons). As the distance increases, the time and therefore the cost increases, but the increase in cost is less in proportion than the increase in distance.

SUMMARY

1. Vehicles most commonly used for stone hauling are the farm wagon and the stone boat. The wagon with a low bed is advantageous for loading. The dump wagon is easily and quickly unloaded if the stones are not to be piled.

2. These means of transportation rank as follows in efficiency: Dump wagon, low wagon, farm wagon, stone boat.

3. The efficiency of hauling stones is about 25 per cent less on broken land than on sod land.

4. The stone boat has advantages in loading, but disadvantages in unloading and for hauling long distances.

5. The time required to remove a unit quantity of stone increases as the length of haul increases, but does not increase in proportion to the distance, because the time for loading and unloading remains the same regardless of change in distance.

6. Where stones are numerous, two men will load a wagon in about 13½ minutes and a stone boat in about 8 minutes.

7. The time for unloading with the different vehicles varies from one minute or less to 15 or 20 minutes.

8. The average size of load for each vehicle is as follows: Farm wagon 28 cubic feet, dump wagon 20 cubic feet, low wagon 19 cubic feet, stone boat 10 cubic feet. A cubic foot of field stone weighs about 100 pounds.

9. The three methods of blasting stones most commonly used are mud-capping, underdrilling, and undermining.

10. Mud-capping can not be properly done unless the stone is entirely out of the ground.

11. Both the volume of a stone and the diameter perpendicular to the position of the charge are important factors in determining the size of charge necessary for mud-capping. Volume, however, has slightly more influence than diameter.

12. The proper size of charge for mud-capping granite boulders may be determined by the following formulas:

For 40 per cent dynamite: $S = \frac{V}{4} + \frac{D}{16} - \frac{1}{4}$

For 60 per cent dynamite: $S = \frac{V}{4} + \frac{D}{40}$

S = size of charge in sticks, V = volume in cubic feet,
D = diameter perpendicular to position of charge in inches.

13. One pound of 40 per cent dynamite is required to accomplish what four-fifths of a pound of 60 per cent dynamite will do. One will be justified in paying 25 per cent more for 60 per cent dynamite than for 40 per cent dynamite for stone blasting purposes.

14. Undermining has the advantage of breaking the stone and throwing it out of the ground with one shot.

15. The cost of burying large boulders without breaking them ranges from 3 to 4 cents per cubic foot of stone.

16. The cost of breaking large boulders and removing the pieces is about 4¼ cents per cubic foot of stone.

17. Stones may be buried in deep pits at a cost of about $2.00 per cord and in trenches at a cost ranging from $2.00 to $4.00 per cord.

18. Stone removal costs per acre vary considerably. The average cost of test plots cleared was $23. The average cost per cord is $2.12.

19. About 65.2 per cent of the total cost of clearing land of stone is man labor, 22.7 per cent is horse labor, and 12.1 per cent is explosive materials.

20. Hauling is the largest item of the cost of stone removal. It constitutes about 75 per cent of the total when the distance is short.