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The Design and Development of a Pasture Furrower for Constructing Contour Furrows Without Destroying the Sod

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THE DESIGN AND DEVELOPMENT OF A PASTURE FURROWER FOR CONSTRUCTING CONTOUR FURROWS WITHOUT DESTROYING THE SOD

BY

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FOR CONSTRUCTING CONTOUR FURROWS
WITHOUT DESTROYING THE SOD

This thesis is approved as a creditable, independent investigation by a candidate for the degree, Master of Science, and acceptable as meeting the thesis requirements for this degree; but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Advisor

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H.T.K.

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INTRODUCTION

The production of grass in pastures of sloping terrain is usually limited by the lack of soil moisture. Soil moisture deficiencies are often encountered even when adequate precipitation is received during the pasture growing season. Moisture which would otherwise be available for plant growth is lost due to a high degree of surface runoff. Surface runoff is that portion of the precipitation that makes its way toward stream channels, lakes, or oceans as surface flow.

Surface runoff will occur when the precipitation has satisfied the demands of evaporation, interception, infiltration, surface storage, surface detention, and channel detention. A negligible quantity of precipitation is intercepted by grass. This amount is even further reduced when pastures are being grazed.

When the rate of precipitation exceeds the rate in which water infiltrates into the soil, surface depressions are filled and overland flow begins. The time required for surface runoff to begin is dependent upon the intensity and duration of rainfall, slope of the land, type of soil and amount of grass cover. Resulting runoff is in equilibrium with the rate of precipitation less infiltration. Before equilibrium is reached a hydraulic head builds up on the surface which contains the volume of water that is in surface detention. A similar build-up of head takes place as the flow moves into defined channels. The volume of water in surface and channel detention is returned to runoff as the runoff rate subsides.

Pastures on sloping land are susceptible to high runoff rates.

This is due in part to the fact that grazing lessens surface detention. When slopes are covered with thick stands of grass, a rather large volume of precipitation will be in surface detention. Reduction of grass height and stand by grazing results in releasing detention water to runoff. When surface detention is reduced, a larger portion of the total precipitation is lost in runoff. This in turn decreases the total volume of water that ordinarily infiltrates into the soil. It is only logical that soil moisture deficiencies caused by high runoff rates will result in reduced grass production. Reduction of forage yields commonly takes place in the form of: thinning of stand, decreased height and vigor, retarded root development and the replacement with less desirable species of grass and weeds.

Numerous conservation practices have been used on pastures and range land in an effort to reduce runoff, conserve moisture, improve plant cover and increase forage yields. Pasture management with respect to proper stocking rate is of paramount importance. The amount of cover left during and after grazing has a tremendous influence on the physical condition of the soil. If pastures are kept closely grazed, the upper soil layers become compacted reducing the porosity of the soil. Close grazing also allows the natural debris to be broken and dispersed leaving little vegetative cover to dampen the destructive forces of raindrops and prevent surface sealing. Under these conditions most of the water is lost in runoff and little is retained for plant growth.

Various mechanical treatments have been used on pastures and range land as a means of reducing runoff and storing water in order to provide additional moisture for growth of grasses. Pasture renovation, subsoiling, pitting and furrowing are operations that have been performed with varying degrees of success. In arid and semiarid regions, renovation of pastures is of little value because of the low annual rainfall. Soil moisture is usually at such a low level that exposure of the top layer of soil would allow much of the remaining moisture to evaporate leaving little for revegetation. Subsoiling does not greatly disturb the surface and is generally performed in an effort to break up an impervious layer and allow water to percolate into the soil. The subsoiler is often used when pasture growth is affected by waterlogging or by restriction of root growth caused by the presence of some form of pan or impermeable barrier.

Contour furrowing and pitting of hill pastures has been an accepted conservation practice. The principle purpose of both contour furrowing and range pitting is to intercept and hold runoff water. By providing storage capacity on the surface, infiltration is encouraged and runoff is reduced. The benefits obtained as a result of these two conservation practices are interrelated. The storage of precipitation at the point of contact with the surface, provides a certain amount of protection from erosion of lower cultivated land. By retaining water on the pasture, water is made available for the growth of grasses. The increased growth of grass will then provide more forage, greater protection for the soil, improved soil structure and increased surface detention.

Pitting of pasture or range land is done with an eccentric disk. An implement commonly used is a large 18-inch, one-way disk plow with alternate disks 20 inches in diameter and mounted 2 inches off center.

This implement scoops out shallow discontinuous pits about 16 inches apart. Water storage capacity of roughly 1,000 cubic feet per acre can be proved by using the pitting operation. Range pitting does not need to be done exactly on contour. Since the pits are small and distributed uniformly, there is little danger of increasing the erosion hazzard.

Contour furrows provide slightly greater runoff control than do range pits. Furrow size and spacing can be adjusted providing adaptability in designing for control of runoff. Furrows are constructed so they are level and have closed ends. The storage potential largely depends upon the land slope, furrow spacing and the size of the furrow. Sod or breaker-bottom moldboard plows are frequently used in the construction of large contour furrows. Smaller furrows spaced closer together are found to be the most effective in controlling runoff and increasing forage production. The small type furrow can be constructed with a field cultivator, lister or toolbar implement equipped with small shovels.

Numerous implements have been modified and furrow openers hand-built in an effort to produce a desirable contour furrow. A large majority of these implements have the undesirable feature of constructing a vertical-walled furrow. This furrow is susceptible to sloughing, which is a breaking down of the furrow profile. The sod removed in the construction of this type of furrow is usually destroyed and spread over the grass between the furrows. This is undesirable in that soil is exposed, promoting weed growth and presenting an unsightly appearance. Grass seed is often placed in the open furrow; even then considerable time is required for the disturbed area to be re-established in grass.

Pasture contour furrows have been constructed on hundreds of acres in South Dakota. Recently an increasing interest shown in this conservation practice has stimulated a need for pasture furrowing research. The immediate objective of the research represented in this thesis is to design and develop a pasture furrowing machine which will construct a smooth, continuous furrow without destroying the sod.

WORK OF OTHER INVESTIGATORS

The Practice of Contour Furrowing

During and immediately following the drought of the "thirties", pastures and range land of the Northern Great Plains were almost completely barren. Contour furrows were plowed on thousands of acres in an effort to reduce runoff and hold precipitation on the land. By so doing the revegetation of unproductive land was greatly accelerated. Since then research findings have aided in the more intelligent design, layout and construction of contour furrows.

The early construction of contour furrows was accomplished primarily with the moldboard plow. Since the breaker-bottom plow was used extensively during this period, it was, therefore, the most logical and convenient implement for contour furrow construction. A road plow was used to construct furrows in Kansas in 1934 (8).* This furrow was quite large making it necessary to use spacings between 16 to 20 feet. Since small furrows spaced close together are more beneficial than the larger furrows on wide spacings, a need was created for new furrowing implements.

Benefits of Contour Furrows

Before 1935 very little research had been conducted which would experimentally substantiate the effectiveness of contour furrowing.

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*Numbers in parenthesis refer to appended references.

In 1938, McNeal (9) made a field survey of some forty farms in five Missouri counties where contour furrows had been constructed. Estimates were made of the percentage runoff after contouring. Assuming a 30 per cent runoff before contouring, McNeal found that runoff after contour furrows were constructed varied from zero to 23 per cent. The average being 6.05 per cent. Based on the reliability of estimates, the findings represented a savings of about 24 per cent of the total rainfall.

McNeal also found that many methods of construction were tried using moldboard plows. Some of the methods used were as follows: Two furrows down, two up and two down, one up and one down, two down and one up, three down and three up and one 18-inch furrow down with a 12-inch plow following in the same furrow also throwing down hill. All of the contour furrows observed were quite large, and considerable sod was destroyed in their construction. Blocking or damming of these large furrows increased their effectiveness. Thus, water is prevented from concentrating at low places along the furrow, reducing the chance of overtopping and maintaining even distribution.

In his survey, McNeal found that the average water holding capacity of contour furrows was 0.65 cubic feet per foot of length. The average spacing was 22.5 feet. Increased grass production was observed primarily near the furrows. Many farmers interviewed expressed the opinion that closer spacing would be much more effective in preventing runoff.

Contour furrowing is an affective means of increasing the productivity of overgrazed pastures and range land. Logan (8) reports that experimental plots in Kansas showed that contour furrows increased the forage growth 29 per cent in 1935. Barnes (4) stated that the amount of grass left at the end of the grazing season on contour-furrowed pastures was 52 per cent over unfurrowed pastures. This research conducted in Wyoming indicates that furrowed pastures provided 22 per cent more sheep days of grazing. In many instances, increased growth of grass and water retention as a result of furrowing eliminates the need for gully-control structures.

Work done at the Texas Agricultural Experiment Station also corroborates the value of contour furrowing as a conservation practice. Furrows three inches deep and spaced 39 inches apart were constructed with a lister. Langley and Fisher (6) stated that yields of grass were increased as much as 3.9 times. They also reported that the grass cover remained green longer during periods of deficient rainfall. Increases in available soil moisture aid in the development of a greater root volume and root penetration. Langley and Fisher noted that furrowed pastures showed a marked decrease in weeds and barren spots. As a result of contour furrowing, desirable species of grass were re-established.

In hilly country, contour furrows can be used to aid in the control of erosion of cultivated land. Runoff water from higher pasture land often floods and badly erodes fields of lower lying areas. By retaining this runoff water on the higher pastures, destructive erosion can be greatly reduced. Powell (10) stated that pasture furrows for this purpose were successfully used in New South Wales. These furrows were constructed with a single-bottom plow and spaced at 20 to 30 feet. He reported that one record storm of 0.80 inches in ten minutes was effectively held.

The Soil Conservation Service is conducting research on rainfall and runoff from native grass areas. This work which was initiated in 1939 is still in progress at the Central Great Plains Experimental Watershed in Nebraska. Hydrological data obtained from these experiments have been helpful in the design and utilization of numerous conservation practices.

During 1940 through 1945 research was undertaken at the above named station to measure the effects of contour furrows on runoff for both heavily and lightly grazed pastures (1). The total annual runoff from this experimental pasture area is shown in Table I. Results indicate that for the six year period, the total runoff was reduced 50 per cent by reducing grazing and 90 per cent by contour furrows. The total runoff from lightly grazed, furrowed pastures was only 1/3 of 1 per cent of the rainfall. Table II shows the effects of grass cover and contour furrows on the peak runoff rate.

Sample results on soil moisture distribution on furrowed and unfurrowed pastures revealed that closer spacing would be desirable. Findings obtained at the Central Great Plains Experimental Watershed indicate that furrows should not be placed more than 12 feet apart for good distribution of soil moisture. The proper spacing will, however, depend upon the land slope, type of soil, and the size of the furrow.

TABLE I. TOTAL ANNUAL RUNOFF FROM PASTURE PLOTS

Treatment	Ave. Slope %	Total Runoff (in inches)						
		1940	1941	1942	1943	1944	1945	6 Yr. Ave.
None (check) Heavily grazed	6.9	0.68	1.36	1.62	1.38	1.72	1.34	1.35
None (check) Lightly grazed	6.8	0.75	1.20	0.55	0.89	0.32	0.34	0.68
Furrowed* Heavily grazed	6.8	0.03	0.10	0.20	0.09	0.27	0.20	0.15
Furrowed* Lightly grazed	7.0	0.14	0.10	0.03	0.05	0.06	0.06	0.07
Annual rainfall at station	---	13.0	26.3	31.8	16.2	29.7	22.6	23.2

* Data are from two plots, one of which had contour furrows horizontally spaced at 10' to 12' intervals, and the other 16' to 18'. The furrows were 4" deep and 6" wide.

TABLE II. MAXIMUM ANNUAL PEAK RATES OF RUNOFF FROM PASTURE PLOTS

Treatment	Ave. Slope %	Peak Rates of Runoff (inches per hr.)						
		1940	1941	1942	1943	1944	1945	6 Yr. Ave.
None (check) Heavily grazed	6.9	0.51	1.11	0.68	1.43	0.95	1.38	1.01
None (check) Lightly grazed	6.8	0.61	1.01	0.27	1.55	0.29	0.61	0.72
Furrowed* Heavily grazed	6.8	0.03	0.06	0.07	0.11	0.14	0.16	0.10
Furrowed* Lightly grazed	7.0	0.03	0.04	0.03	0.11	0.05	0.13	0.07
Annual rainfall at station	---	13.0	26.3	31.8	16.2	29.7	22.6	23.2

* Data are from two plots, one of which had contour furrows horizontally spaced at 10' to 12' intervals, and the other 16' to 18'. The furrows were 4" deep and 6" wide.

Pasture Furrowing Machinery

Pasture contour furrows may be constructed with various implements commonly found on the farm. The moldboard plow is quite suitable because of its sturdy construction and ability to withstand large forces. Still frequently used to construct contour furrows, this implement is desirable in that it will operate satisfactorily under varied soil conditions. Little difficulty is encountered in obtaining desired depth control and penetration.

The furrow profile depends upon the depth of operation and moldboard size. Sod is generally inverted and thrown in the down hill direction forming a levee or ridge. This provides large storage capacity since both the furrow and the furrow slice are used to retain water. Wide spacings are ordinarily used because of the large storage capacity and width of the furrow.

Some undesirable features of contour furrows constructed with a moldboard plow are:

1. Considerable sod is destroyed and established grass killed by the inverted furrow slice.
2. Exposed soil is vulnerable to wind erosion, washing and weed growth.
3. Regrowth of grass over the furrowed area usually requires a long period of time.
4. The ridge formed by inverted sod is often broken and not uniform in height.
5. Travel across furrowed areas is very difficult because of the high ridges and deep depressions.

6. Wide spacing, associated with this type of contour furrow, does not provide even distribution of soil moisture.

In order to overcome some of the objectionable aspects mentioned above, numerous other implements have been employed. One such implement is a chisel plow, which according to Lindsay (7) could actually replace the moldboard plow for water-retention work. The lister and middlebuster are also adaptable for pasture furrow construction. Contour listing of native grass pastures was successfully carried out in Texas (6). In addition to these implements, field cultivators and toolbars equipped with small shovels or furrow openers are quite suitable. Generally the equipment which the operator has available will be used.

These implements have the decided advantage over the moldboard plow in that their power requirements are less. The furrows are small and therefore make it easier to travel across treated areas. Since small furrows are spaced closer together than the larger furrows, retained water is more uniformly distributed. Regrowth of grass within the smaller furrow takes place in a relatively short time.

The small type furrows may range in size from 3 to 8 inches in width and from 3 to 6 inches in depth. As with the larger furrows, spacings are determined by the amount of runoff to be intercepted. Water is held in the furrow without the aid of a ridge below the furrow. Sod removed from the furrow is not used to form a ridge but is scattered and disposed of on the grass above and below the furrow. Figure 1 shows the small type furrow being constructed with a tool bar implement. Figure 2 shows the same furrows three months later. Note the broken

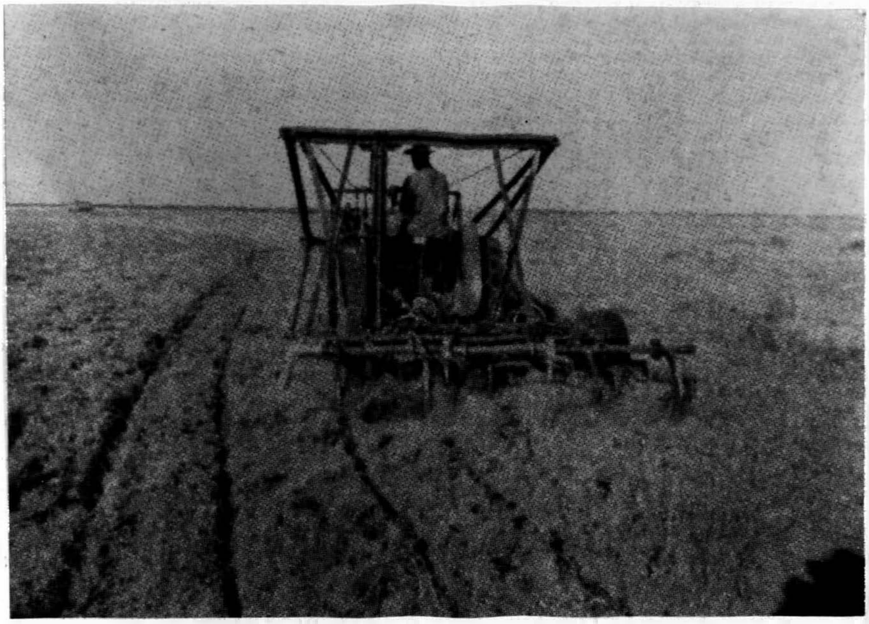


Figure 1. Small Type of Contour Furrows Being Constructed with Tool Bar Equipment in June 1948

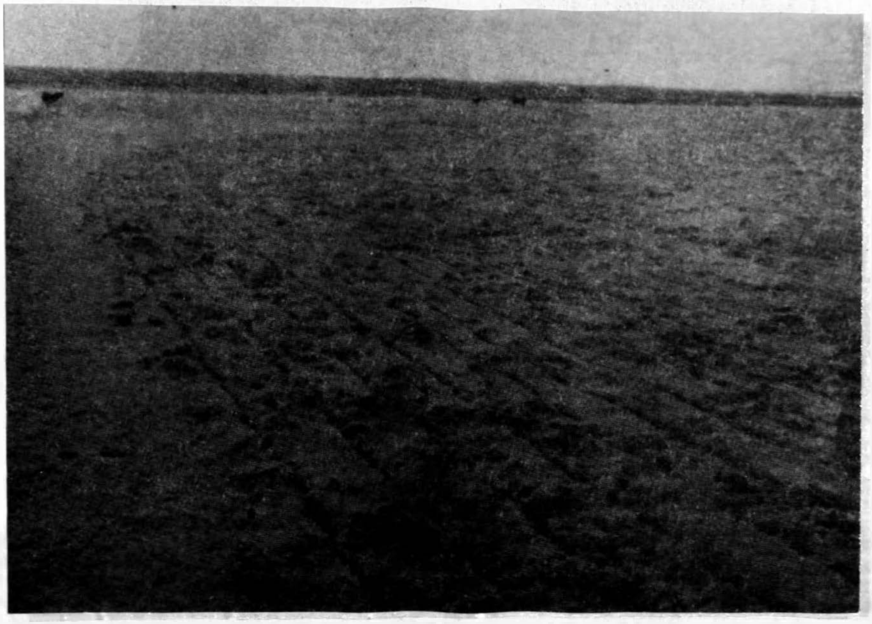


Figure 2. Same Contour Furrows as Shown in Figure 1, Three Months After Construction

pieces of sod between the furrows. This is undesirable in that the pasture surface is left rough and unsightly. A packer or harrow is frequently employed to break-up the wasted sod pieces.

Sloughing and silting-in takes place more readily when small contour furrows are used. This naturally causes the furrows to lose their effectiveness. As soon as the old furrows no longer retain sufficient water, they must be reconstructed or new furrows constructed between the old ones. The expected life of the small type furrows varies considerable, depending upon the grazing intensity, type of soil, and other related conditions.

Small type furrows on heavily grazed pastures are quite prone to sloughing. The straight furrow walls are loosely held to the surface layer by poorly developed root structure. Treading livestock and the forces imposed by alternately wetting and drying break off pieces of sod which fall into the furrow. Sloughing results in reduced furrow depth and increased furrow width.

Silting-in of contour furrows is primarily responsible for their becoming ineffective. Poor grass cover due to overgrazing greatly enhances this process. Fine fractions of soil are eroded by rain droplets and washed into the furrow. The presence of sod fragments, removed from the furrows during their construction, also provides additional material which may be carried by water back into the furrow. It would therefore be desirable if contour furrows were constructed without destroying any of the protective sod mantle.'

One of the first machines designed to construct a contour furrow without destroying the removed sod is described by Logan (8).

This machine, built by two Soil Conservation Service engineers, proved quite satisfactory. The machine frame was made out of a two-bottom tractor plow. The main axle was cut and relocated in such a way as to place the wheels on an even plane. In order to fasten a U-shaped knife to the plow, the rear beam was cut off and moved forward. Curved rods attached to the knife lifted the sod and delivered it right side up on the lower side of the furrow. The finished furrow cross-section is shown in Figure 3.

Bonding between the sod strip and ground beneath was accomplished by using a small grader blade to remove grass where the strip was to be placed. In this way roots could easily re-enter the soil below. Uniformity on levee height and good sealing of the sod strip provided protection against overtopping and seepage.

Furrows constructed with this machine had large storage capacities; however, crossing with vehicles was extremely difficult because of the high ridge and deep rectangular depression. Even though the removed sod was not destroyed, these furrows had vertical walls and considerable exposed subsoil.

In 1937 an experimental machine was built which would construct a ridged contour furrow leaving very little soil exposed. According to Collins and Bloom (5), right and left furrow slices were cut and lifted but not broken away at the outer edges. The slice on one side was cut eight inches deep and the adjacent slice cut four inches deep. Immediately following and beneath the four inch slice, an attached plow bottom cut four inches deeper and threw soil under the eight inch slice. Sod slices were held up with steel slats while soil was being moved to

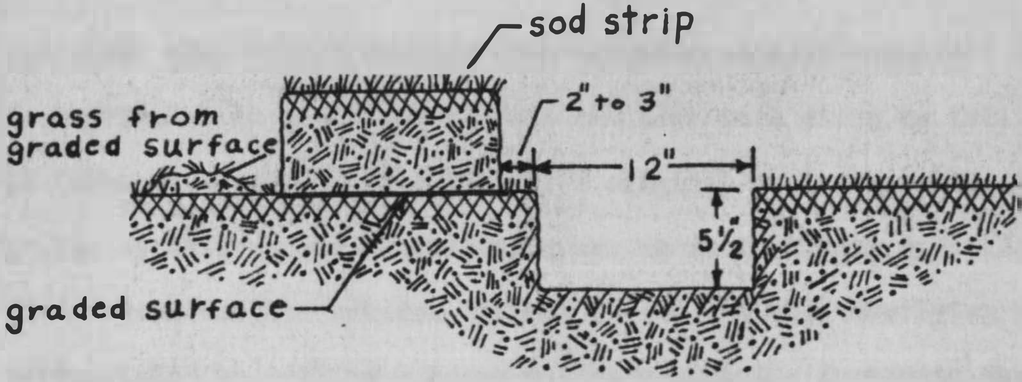


Figure 3. Cross-Section of Contour Furrow Showing Sod Strip Removed and Placed on the Lower Side of the Furrow.

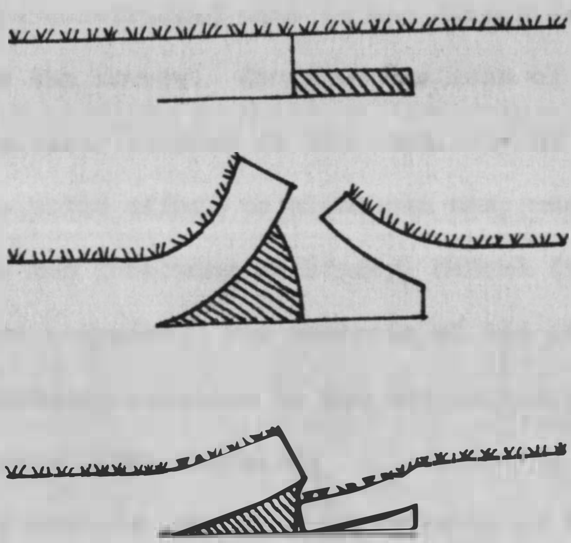


Figure 4. Cross-Sectional Diagram Illustrating the Work of the Contour Furrowing Machine Described by Collins and Bloom.

the lower side of the furrow. The transferred soil supported the eight inch slice at an angle and allowed the four inch slice to fall into position three inches lower than its original position. Consecutive phases of this furrow construction are shown in Figure 4.

Good contact between the sod slices and the underlying soil was accomplished by pulling a heavy roller behind the furrowing machine. This roller also aided in maintaining a ridge at a uniform height. The effective height of the finished furrow was about six inches, the ridge being approximately nine inches above the furrow bottom. Because of the high ridge this furrow had large storage potential.

An objectionable feature of this furrowing implement was that furrows could be constructed only in one direction in order to maintain the ridge below the furrow. Considerable loss of time and increased costs was encountered because of the necessity of return trips.

In a concerted effort to eliminate many undesirable aspects of contour furrows and furrowing machinery, McNeal (9) made a survey of several Missouri counties. His analysis of the trends and needs of this conservation practice resulted in the design and construction of a successful pasture furrowing plow.

McNeal's machine consisted essentially of an 18-inch tractor sulky plow. The furrow opener was composed of both a right-hand and left-hand bottom fastened together to form a large lister. The upper part of the frogs were removed and the rear parts of the moldboards cut off so as to lift the furrow slices more gently and avoid inverting them. Steel slats attached to the rear of the moldboards held the sod slices up while a disk removed soil from under the upper furrow slice and threw it beneath the lower furrow slice. In this way the ridge and furrow were covered with the sod slices allowing grass to continue growing.

There is a limited number of implements especially designed to construct pasture contour furrows. Almost all these implements have been hand-built. Machines generally employed in this important conservation practice are those designed for cultivated land. It would therefore be desirable if special contour furrowing machines were designed and produced commercially.

STATEMENT OF THE PROBLEM

At the present time there are no implements manufactured commercially for the sole purpose of constructing pasture contour furrows. The need for machines of this nature has been expressed by numerous people interested in this conservation practice in South Dakota.

Many land owners in South Dakota are reluctant to furrow their pastures because of the undesirable characteristics of the furrows commonly employed. In some localities, equipment that will build a satisfactory contour furrow is not available. The problem encountered, therefore, is to design and develop a pasture contour furrower that will:

1. Meet the present needs and trends of this conservation practice in South Dakota.
2. Be relatively simple in design and inexpensive to build.
3. Mount easily on most trailer type toolbar implements or tool carriers in common use.
4. Have a draft light enough to be pulled by a three-plow tractor.
5. Construct a contour furrow without destroying any sod.

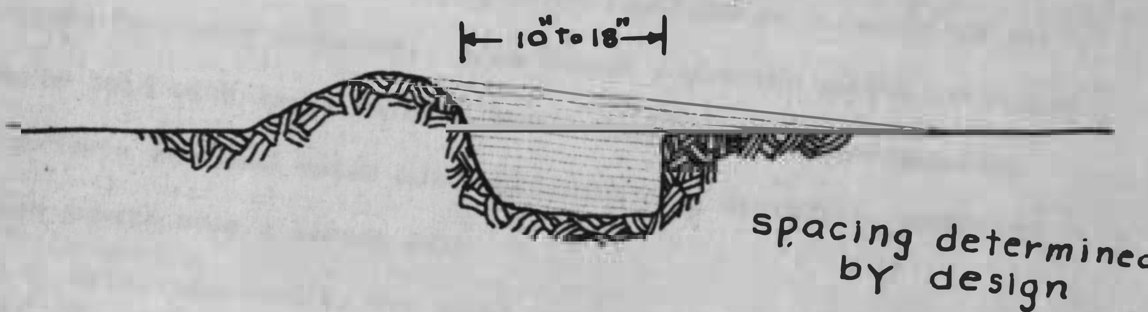
REQUIREMENTS OF THE MACHINE

The practice of pasture contour furrowing serves two main purposes: to increase vegetive response and to reduce runoff. If increasing forage yield is the primary purpose, an implement which will construct small furrows at close intervals is usually employed. However, if reducing runoff is of greatest concern, machinery capable of constructing relatively large furrows will be selected. Both the small and large type furrows, frequently employed, have many undesirable features. Hence, the principle requirement of the machine developed in this project is that it construct furrows that will fulfill both purposes mentioned above and also eliminate many objectionable features.

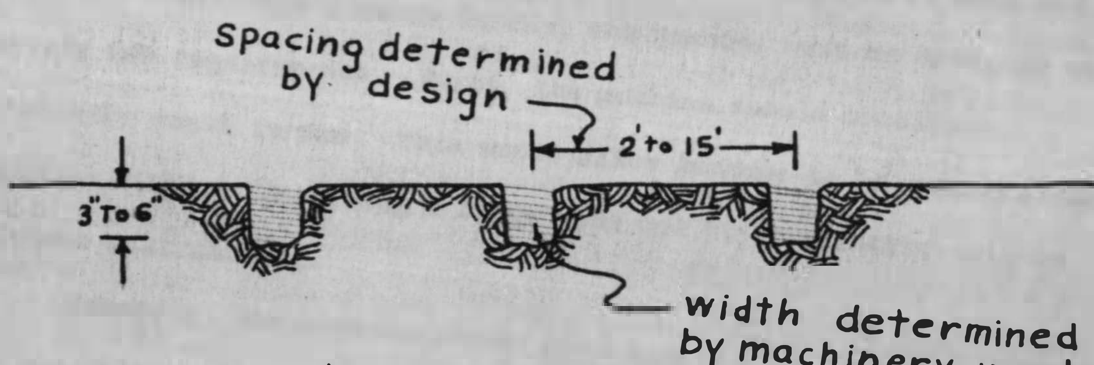
Furrow Size and Spacing

The early practice of pasture furrowing was done almost entirely with the moldboard plow. Furrow sizes varied somewhat with the size of the moldboard. Greater size was effected by making numerous passes on the same furrow. These furrows had large water storage capacity both above and below the surface level of the ground. Because of their large width and depth, furrows were spaced from 20 to 50 feet apart.

Large furrows placed on the level contour are capable of empounding large volumes of runoff water. A great portion of this water is retained by the ridges created with inverted sod (Figure 5.) Extreme care must be exercised in the construction of this type of furrow since a low place in the levee or depression will greatly increase the danger of erosion damage. For this and other reasons previously stated,



a. FURROW CONSTRUCTED WITH MOLDBOARD PLOW



b. SMALL TYPE FURROW

Figure 5. Cross Section of a Large and Small Type Furrow

large type contour furrows and wide spacings are not used as extensively as in the past.

The present trend of small furrows spaced closely together is due primarily to the greater benefits realized as a result of the pasture furrowing practice. Even though a greater volume of runoff can be held with large furrows, small furrows and close spacings distribute retained water more uniformly and, therefore, stimulate grass growth over a larger area.

Water retained by the small type furrows is held in a depression below the surface level of the ground (Figure 5.) Since less water is held in each furrow the danger of erosion due to overflowing is greatly reduced.

In order to retain some of the desirable aspects of both the large and small type contour furrow, the machine must be designed to satisfy two requirements. First, the machine should construct a relatively small furrow. This would allow furrows to be spaced close together without disturbing a large area and still maintain uniform moisture distribution.

Secondly, the machine should also construct a furrow with large storage potential. To accomplish this, without increasing the furrow size, earth removed from the depression must be used to form a levee. In this way sod ordinarily destroyed in forming small furrows is utilized to good advantage.

Furrow Characteristics

A desired characteristic of pasture contour furrows is stability. The effectiveness and longevity of furrows will depend upon the furrows ability to retain their shape over a period of years. Factors such as soil texture, soil structure, grass cover and furrow shape greatly influence furrow stability. Much can be done, however, to minimize furrow instability. It was, therefore, considered desirable that the contour furrowing machine should construct a relatively permanent furrow.

In meeting this requirement the machine must construct a furrow without destroying the sod. Two sod slices must be cut and lifted while underlying soil is shifted to form the desired furrow shape. The sod slices must then be replaced over the new surface. In this way the furrowed area will retain its sod covering allowing the grass to continue growing.

The finished furrow should appear as a semicircular depression immediately above a rounded ridge. By eliminating sharp cornered furrow walls sloughing is reduced and lighter textured soils are more easily held in place by the sod covering. Since little soil remains exposed, wind erosion is also minimized during a dry season.

The furrows should be resistant to damaging forces imposed by treading livestock and vehicle traffic. It is also important that grazing animals be able to cross over furrows easily without danger of injury. Sodded furrows that have gently curved ridges and depressions will best satisfy these requirements.

Design Simplicity

Another requirement of considerable importance is simplicity. Machines that are not complex are generally more trouble free and less expensive to produce.

In order to keep the initial cost low, the pasture contour furrowing machine should be designed as an attachment to be mounted on trailer-type toolbars or tool carriers. This is desirable because tool carriers are readily available and frequently used for various other tillage operations.

By attaching the contour furrowing machine to a trailed tool carrier, the machine could be pulled by a tractor through a single hitch point. Trailer-type implements are usually more easily attached and detached than are three-point hitched implements. A factor to be considered also, is that many tractors in use today are not equipped with three-point hitches.

Attaching the contour furrower to a tool carrier should be easy and require very little time. This can be accomplished by fastening the furrower standard to the tool carrier at three points. The upper end of the standard should be clamped securely to the tool carrier with a toolbar bracket. The other two fastening points should consist of two braces angling forward and upward from the lower part of the standard to the main frame of the tool carrier. These braces would serve to stabilize the standard and transmit most of the force to the tool carrier.

Serviceability of machine parts must also be considered. Parts needing repair or replacement should be easily removable. To accomplish this the component parts of the machine were assembled and held in place with bolts wherever possible. Welds were employed only where the use of bolts is not sufficiently strong or otherwise not feasible.

In addition to ease of servicing and repairing, the machine should be adjustable. Satisfactory operation is more easily obtained if the machine can be properly adjusted to meet varying soil conditions. This feature is perhaps even more important in a prototype machine because of the need for greater control in the process of testing an operating analysis.

Ease of Operation

The operation of this pasture contour furrower should be convenient and require little effort on the part of the operator. All major control levers should be located within easy reach from the tractor seat.

Lifting and lowering of the furrowing tool should be performed hydraulically or with a ground power lift. Since furrows usually stop short of rills, roads and drainageways, it is important that the machine be able to quickly lift and lower without having to stop the forward motion of the tractor.

In order to save time and lower furrow construction costs, the machine should be reversible. Therefore, the furrowing tool must be designed to shift underlying soil in either direction. This would always permit soil to be moved in the downhill direction and eliminate idle travel necessary when one-way implements are employed. The machine should be reversed by simply moving a lever to the proper position, and by mounting this lever within easy reach of the operator; reversal can be performed without having to stop and dismount from the tractor.

Convenience and ease of operation are important consideration in the design of most machines. Proper emphasis given to these factors often improves operator's safety as well as comfort. Adequate provisions should therefore be made to incorporate these features into the design of a pasture contour furrower.

DESIGN AND DEVELOPMENT

During the early planning stage of this project, various types of pasture contour furrowing machines were examined and observed in an attempt to obtain helpful design information. These machines are presently being used in South Dakota counties east of the Missouri River. Particular interest was focused on machines that were hand built or modified tillage implements. A planned effort was also made to examine the completed work of these machines.

Information received during this inspection tour revealed that the main objection to these machines was their destruction of valuable sod. Hence, it was decided to place considerable design emphasis on developing a machine which would be capable of constructing furrows without destroying any sod. Other requirements previously outlined in this report are also given full consideration in the design of this pasture furrower.

General Features

This machine is designed to construct contour furrows on native grass and tame pastures. No attempt has been made to design it for use in cultivated land or grassed fields where a sod stratum has not developed.

Large resistance forces are encountered in cutting, lifting and inverting sod. The magnitudes of these forces are unknown since they vary tremendously with changing soil conditions. In addition to these forces the presence of stones and other obstructions impose destructive shock loads to the machine. The machine is built of a sturdy construction believed to adequately withstand large forces resulting from pasture furrowing.

The machine consists primarily of the main furrowing tool attached to a conventional eight foot trailed tool carrier. Figure 6 shows a general view of the machine. A remote hydraulic cylinder is used to raise and lower the furrowing tool and to control the working depth

Rigidity and strength are obtained by using a heavy steel standard. The standard or shank is securely fastened to the tool carrier with an easily detachable mounting bracket. Two braces connecting the lower part of the standard to the tool carrier frame provide additional strength and rigidity.

The furrowing tool is composed of a 43 inch V-blade, sod rack, small scarifying blade and a 12 inch disk. Two sod slices, three to five inches thick, are cut out with the V-blade and gently lifted by the sod rack while a disk mounted beneath the sod rack removes soil from under the upper slice forming a ridge beneath the lower slice. The sod slices remain attached at their outer edges and are lowered into place over the ridge and depression.

Since underlying soil must always be thrown beneath the lower sod slice, the disk assembly is designed as a reversible unit. The disk is mounted on the end of a beam which pivots horizontally on two bearings immediately behind the tool standard. A hand lever is used to swing the disk beam under either the left or right sod rack. Disk angle adjustments are made with a second lever which rotates the disk

Figure 6. General View of the Pasture Furrowing Machine

Figure 7. General View of the Pasture Furrowing Machine with Box Provided for Accomodating the Addition of Extra Weight

and disk bearing assembly in a pipe bearing at the outer end of the beam. Provisions are also made for adjusting the tilt angle of the disk.

In order to loosen soil beneath the sod slices and reduce the strain on the disk assembly, a small scarifying blade is mounted behind the main tool standard. This blade operates five to six inches below the V-blade. It need not be used if the soil is loose or moist. The scarifying blade also serves to loosen small rocks before they come in contact with the disk.

The sod cutter consists of a large V-blade or V-shaped sweep of the type commonly used for subsurface tillage. A sod rack in the form of curved rods is bolted to the heel of the blade in order that the sod slice will be gently lifted off the blade surface without breaking. A conventional rolling coulter is mounted in front of the V-blade to make a smooth vertical cut to separate the sod slices evenly.

In hard and heavily sod-bound pastures, additional weight is needed to force the V-blade into the soil. To accommodate the adding of extra weight a 2 x 3 foot box is placed on top of the tool carrier frame as shown in Figure 7. Sandbags, stones, or other ballast may be placed in the box as weight is needed.

V-Blade and Sod Rack

The primary function of the V-blade is to cut two sod slices in such a manner as to preserve the grass and prevent breakage of the sod layer. Sod slices must be lifted about one foot above the cutting edge of the blade in order to provide space for the disk assembly to function beneath the lifted sod. It is also important that the sod slices remain attached to the surface at their outer edges. This prevents the slices from sliding off to the side of the sod racks.

The blade on this machine is designed to cut a width of 43 inches. Reducing the width of cut results in an increased angle through which the sod slices must be lifted to obtain the desired clearance. Material used in the blade construction was taken from an experimental stubble mulch sweep made of high carbon steel. This blade is 3/8 inch thick and tapers to a sharp forward cutting edge.

The two wings of the blade are welded together to form a V-angle of 82 degrees. This angle was selected rather than 90 degrees in order to improve cutting and root shedding characteristics (2). Suction is provided by placing the rear side of the blade two inches above the cutting edge. A triangular shaped 3/8 inch steel plate is welded between the blade wings to strengthen the blade and provide a base plate for mounting the blade to the standard.

Figure 8 shows the V-blade and tool standard mounting. The standard is fastened to the blade with two 2 x 2 x 3/8 inch angles. Four 5/8 inch bolts hold the angles to the base plate, and two 5/8 inch bolts run horizontally through the tool standard and both angles. A 1 x 6 inch opening in the base plate permits the tool standard to extend through to the lower surface of the plate. A 2 x 2 x 1/4 inch angle bolted to the base plate, directly behind the tool standard, further increases the rigidity of the blade. This member also supports the lower bearing of the disk beam assembly.

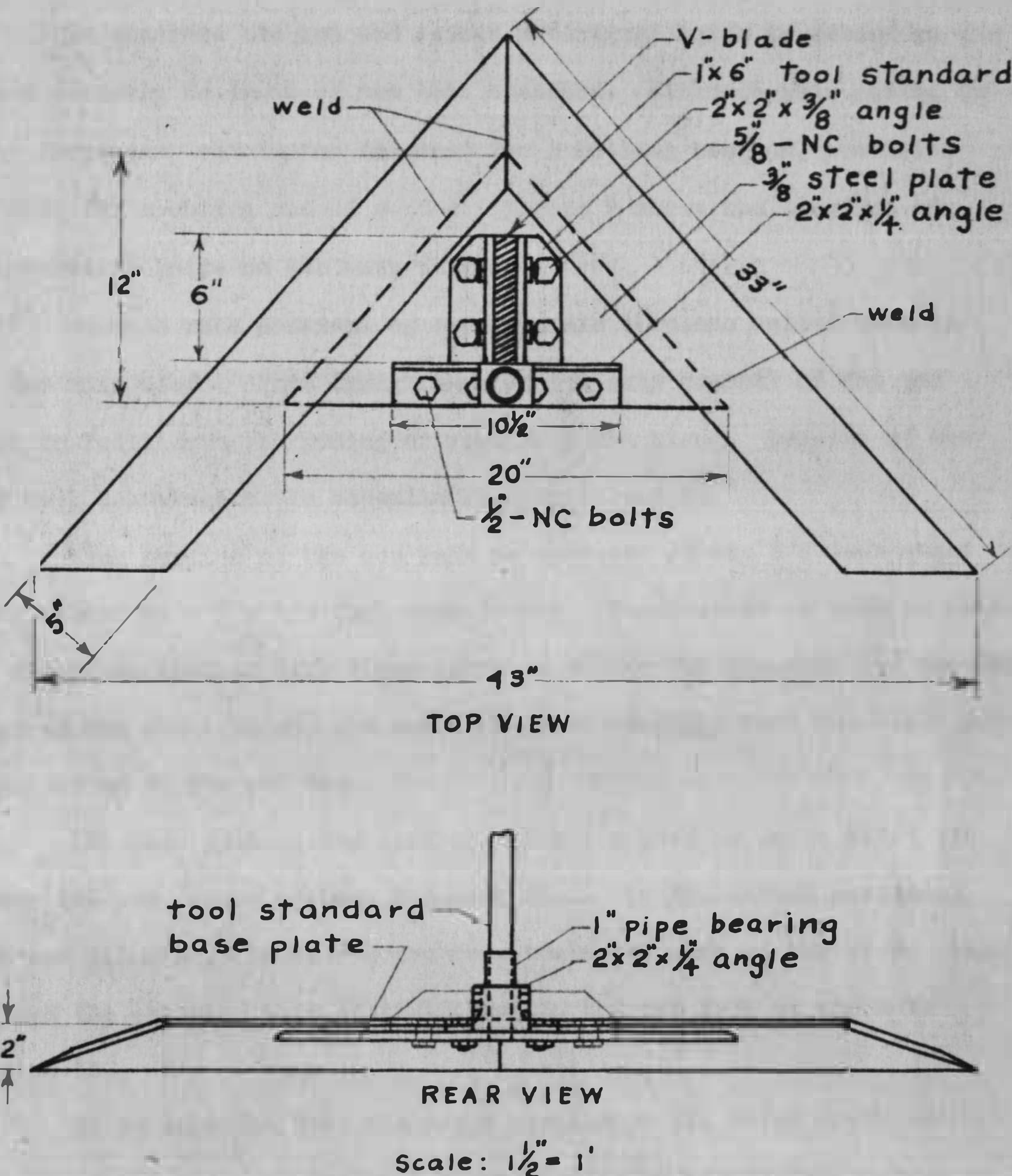


Figure 8. V-Blade Sod Cutter

To separate the two sod slices a vertical knife is welded to the blade directly in front of the tool standard. Although this knife, in many instances, eliminates the need for a rolling coulter, provision is made for mounting one if needed. Figure 9 shows the location of the vertical knife on the main V-blade.

The sod rack consists of two separate sections bolted directly to the main blade. This design permits the easy removal of the sod rack to facilitate sharpening or repair of the blade. Details of the sod rack construction is shown in Figures 11 and 12.

Each section of the sod rack is composed of six 5/8 inch steel rods welded to a 2 x 1/4 inch steel strap. The section is held in place on the blade surface with three carriage bolts. By tapering the forward edge of the steel strap, the sod will slide smoothly over the blade surface and on to the sod rack.

The rods forming the rack are gently curved so as to raise and lower the sod slices without breaking them. In the lifted position, the sod slice also slopes upward from the outer ends of the blade wings toward the center. This lateral slope in the sod rack is shown in Figure 10.

It is expected that the major portion of the total draft requirements of this machine will be attributed to the V-blade. Resistance forces exerted on the blade by the soil during the furrowing operation will depend upon such factors as the soil type and condition, type of vegetative cover, sharpness of the blade, speed of forward motion, and depth of operation.

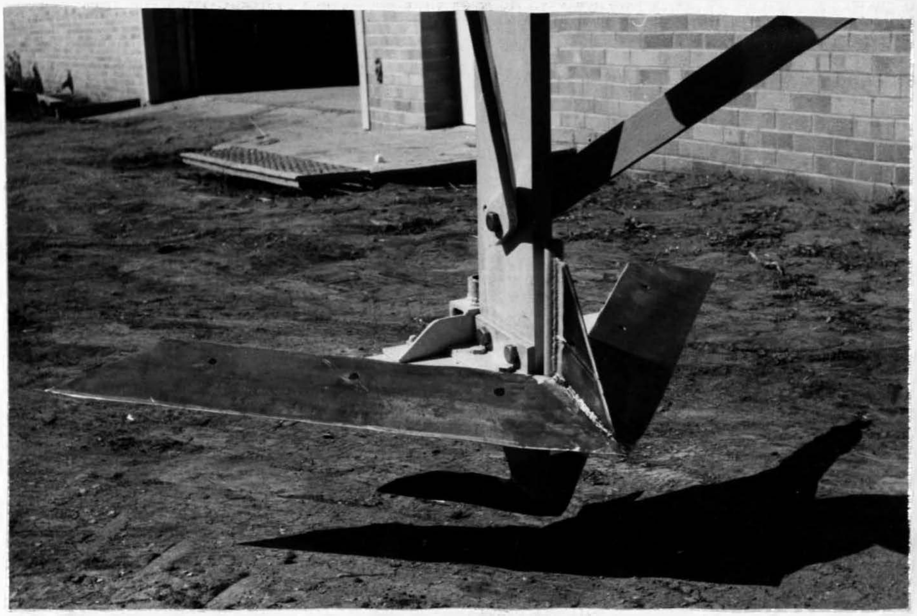


Figure 9. Relative Location of the Vertical Knife on the V-Blade

Figure 10. Rear View of Pasture Furrower Showing Lateral Slope of the Sod Rack

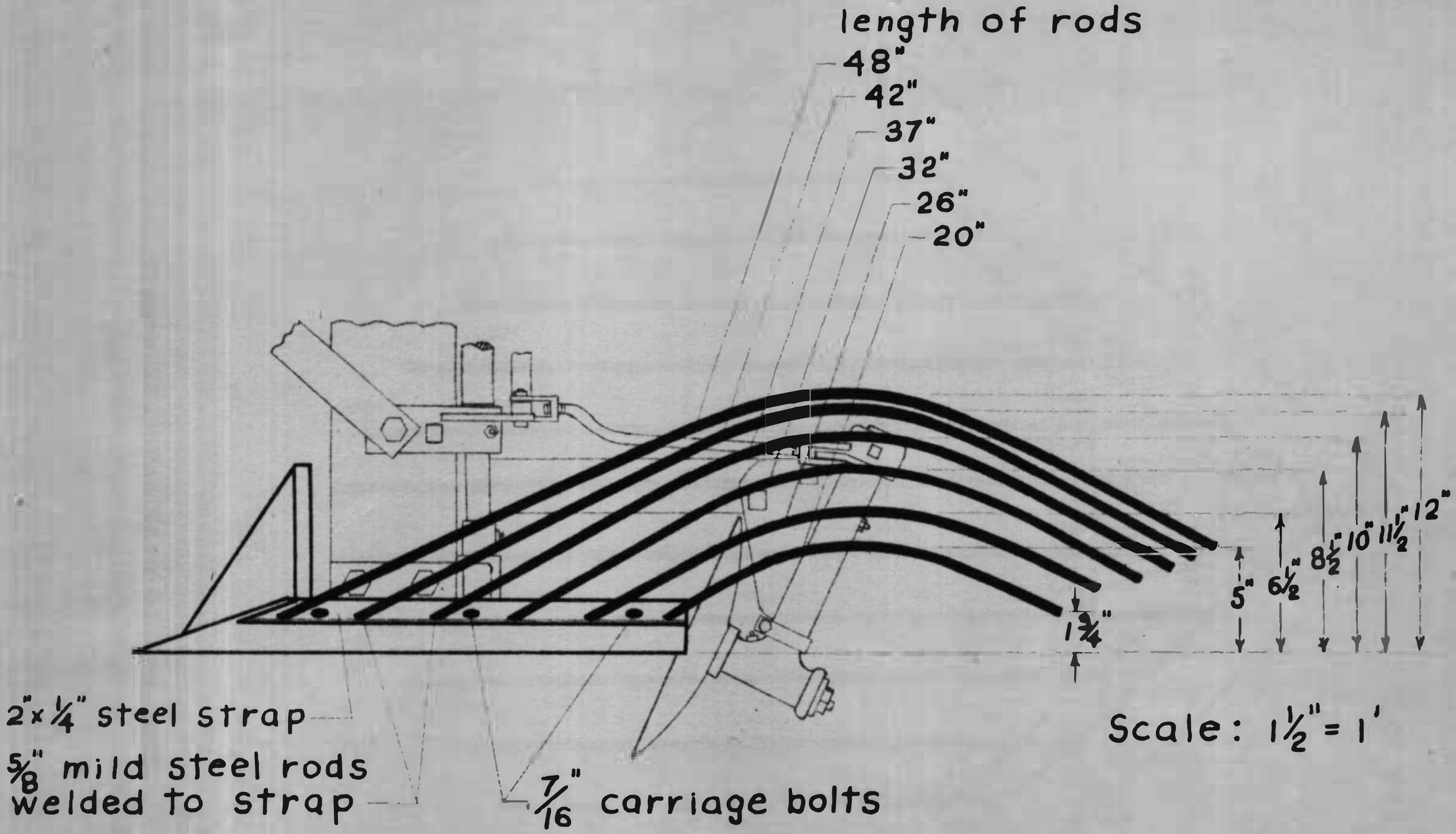


Figure 11. Side View of Sod Rack

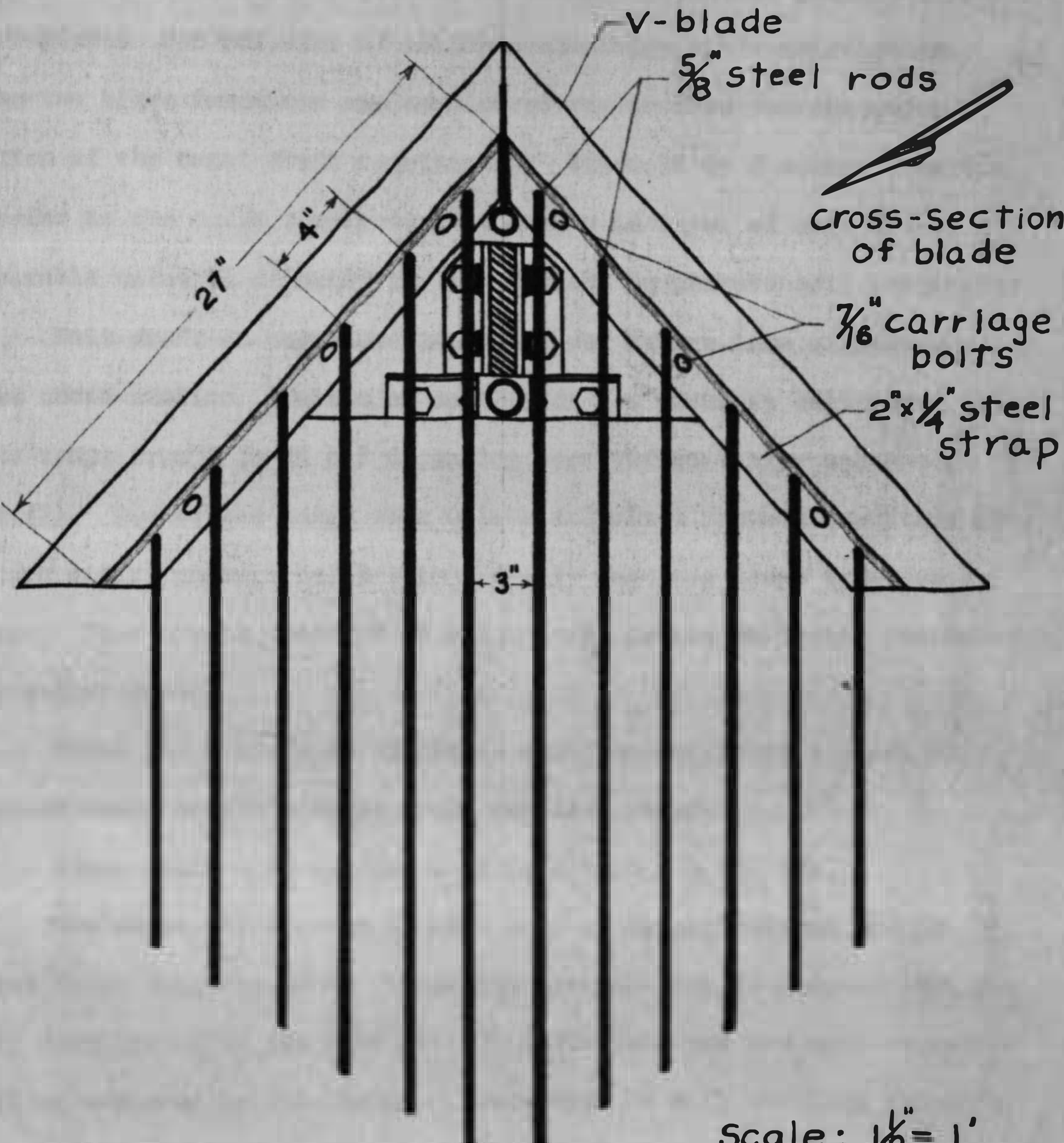


Figure 12. Top View of Sod Rack

Cutting and initial lifting of the sod slices is performed by the V-blade. For purposes of making preliminary draft calculations, these two blade functions are considered responsible for the major portion of the total draft requirement. Since it is a common practice to refer to the draft requirement of a plow in terms of unit draft, a comparable value is selected for the V-blade in pasture soil conditions.

Unit draft is expressed in pounds per square inch of furrow slice cross section. Values of unit draft for plows in cultivated soils range from 3 to 20 psi depending upon the soil type and condition (2). Due to the large root volume and often compact condition of pasture soils, pasture cultivation usually requires large tractive forces. Thus a unit draft of 20 psi is used in the following preliminary calculations.

Since the V-blade is 43 inches wide, operating at a depth of 4 inches would create a total draft requirement of:

Total draft = 20 lbs/in^2 x 43 in x 4 in = 3,440 lbs.

The above calculation is used only as an estimate of the expected draft requirement of the entire machine. It is assumed that the draft contributed by the scarifying blade, disk, and sod rack is very small as compared to this value. Variations in soil moisture probably have the greatest influence on the unit draft. Further analysis of the machine's draft requirement is made in the field test.

Tool Standard and Mountings

The tool standard and mountings transmit the forces exerted on the furrowing tool to the tool carrier. Since the magnitudes of these forces are not known, the standard and mountings must be designed to withstand and estimated maximum load.

Maximum loading will probably result from shock imposed by obstructions such as stones. The amount of impact force exerted on the tool standard and its mountings will depend upon the ability of the V-blade to transmit this force. It is also expected that large, firmly embedded obstructions will damage the blade. Thus in some instances the blade may receive destructive blows without subjecting the tool standard to a greatly increased load.

The estimated draft requirement of the machine is assumed to be due primarily to soil resistance acting on the V-blade. Therefore, the tool standard and mountings are designed on the basis of an assumed load acting upon the blade and resulting from an encountered obstruction. Forces acting on the tool standard are shown schematically in Figure 13. A shock load of 8,000 pounds is assumed as being exerted horizontally on the tool standard at A. Forces exerted on the standard by the weight of the tool carrier and the vertical component of the soil reaction are neglected in this analysis since they are small as compared to the impact load. Two braces are attached to the standard at B and to the tool carrier at C and D. The upper end of the tool standard is fastened to the toolbar mounting bracket at E. The magnitude of the forces acting on the tool standard is calculated as follows:

$$\Sigma M_e = 0$$

$$T \sin\theta \times 17.5 \text{ in} - 8{,}000 \text{ lb} \times 26 \text{ in} = 0$$

$$T = \frac{8{,}000 \text{ lb} \times 26 \text{ in}}{0.76 \times 17.5 \text{ in}} = 15{,}620 \text{ lb}$$

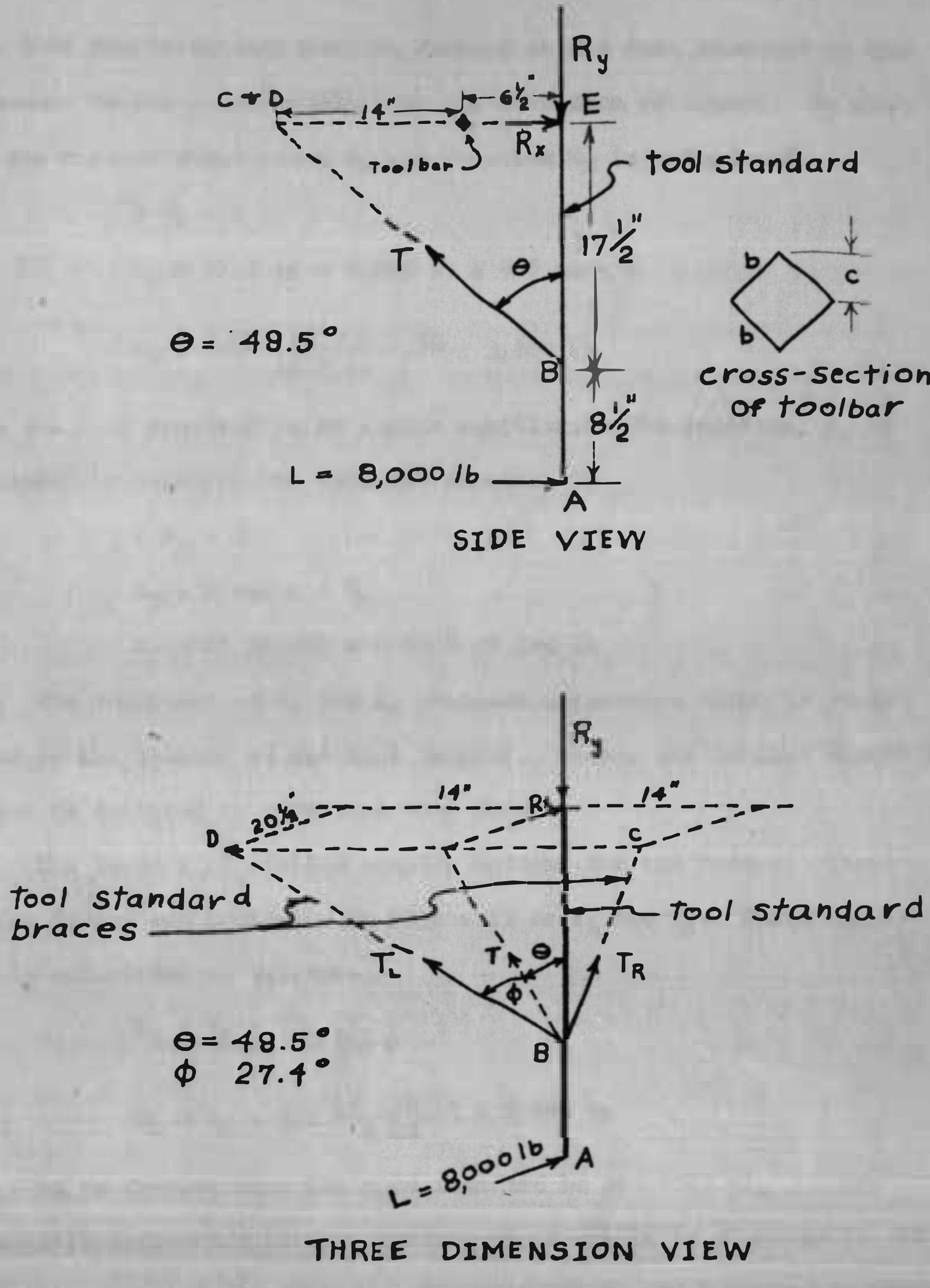


Figure 13. Schematic Diagram Showing the Forces Acting on the Tool Standard as a Result of an Impact Load of 8,000 Pounds

Where T is the force that must be exerted on the tool standard by the two braces in the plane parallel to the direction of travel. By summing the moments about point B, the reaction R_x is calculated.

$$\Sigma M_b = 0$$

$$R_x \times 17.5 \text{ in} - 8{,}000 \text{ lb} \times 8.5 \text{ in} = 0$$

$$R_x = \frac{8{,}000 \text{ lb} \times 8.5 \text{ in}}{17.5 \text{ in}} = 3{,}890 \text{ lb}$$

Since the tool standard is in static equilibrium the reaction, R_y is calculated by equating the vertical forces.

$$\Sigma F_y = 0$$

$$R_y - T \cos\theta = 0$$

$$R_y = 15{,}620 \text{ lb} \times 0.65 = 10{,}160 \text{ lb}$$

The resultant of R_x and R_y produces a reaction which is transmitted to the toolbar of the tool carrier. Hence, the toolbar mounting bracket is designed to withstand this force.

The force T is divided equally between the two braces. These tension forces are indicated in Figure 13 as T_L and T_R. Their magnitude is calculated as follows:

$$T_L = T_R = 1/2 \frac{T}{\text{Cos}\,\phi}$$

$$T_L = T_R = 1/2 \frac{15{,}620 \text{ lb}}{0.88} = 8{,}800 \text{ lb}$$

It is desired that the tool standard be extremly rigid. Any appreciable deflection of the standard would result in a change in the level adjustment of the V-blade. For this reason the standard is much heavier than would be necessary to remain within the working limits of the material. The standard consists of 1 x 6 inch (SAE 1015) steel bar. Three 5/8 inch bolts fasten the standard to the toolbar mounting bracket. The toolbar mounting bracket is designed to rigidly support the upper end of the tool standard. Four 3/4 inch bolts are used to clamp the bracket to the toolbar. This arrangement permits the furrowing tool to be quickly mounted on most conventional toolbar carriers.

The mounting bracket consists of four 2 x 2 x 1/4 inch angles and two 9 x 6 x 3/8 inch steel plates. An angle is welded to each plate and notches cut to fit a 2 x 2 inch tool bar. Construction details are illustrated in Figure 14. The force acting on the mounting bracket, due to the assumed impact load of 8,000 pounds, is a reaction force equal to the resultant of R_x and R_y. (See Figure 13.)

Denoting this force as R, its value is calculated as follows:

$$R = \sqrt{R_x^2 + R_y^2}$$

$$R = \sqrt{(3,[illegible]90)^2 + (10,160)^2} = 10,900 \text{ lb}$$

The toolbar is supported in two places by the tool carrier frame. These supports are 28 inches apart. For purposes of calculating an approximate bending stress, the toolbar is considered to be a simply supported beam. The toolbar bracket is mounted midway between the frame supports and exerts an upward force equal to the component R_y. Neglecting the weight of the tool carrier, the bending moment resulting from R_y is

$$M = 1/2\ R_y \times 14 \text{ in}$$

$$M = 1/2 \times 10,160 \text{ lb} \times 14 \text{ in} = 71,120 \text{ in-lb}$$

Stress due to this bending moment is a maximum at the upper and lower corners of the toolbar. The stress is calculated with the following "flexure formula."

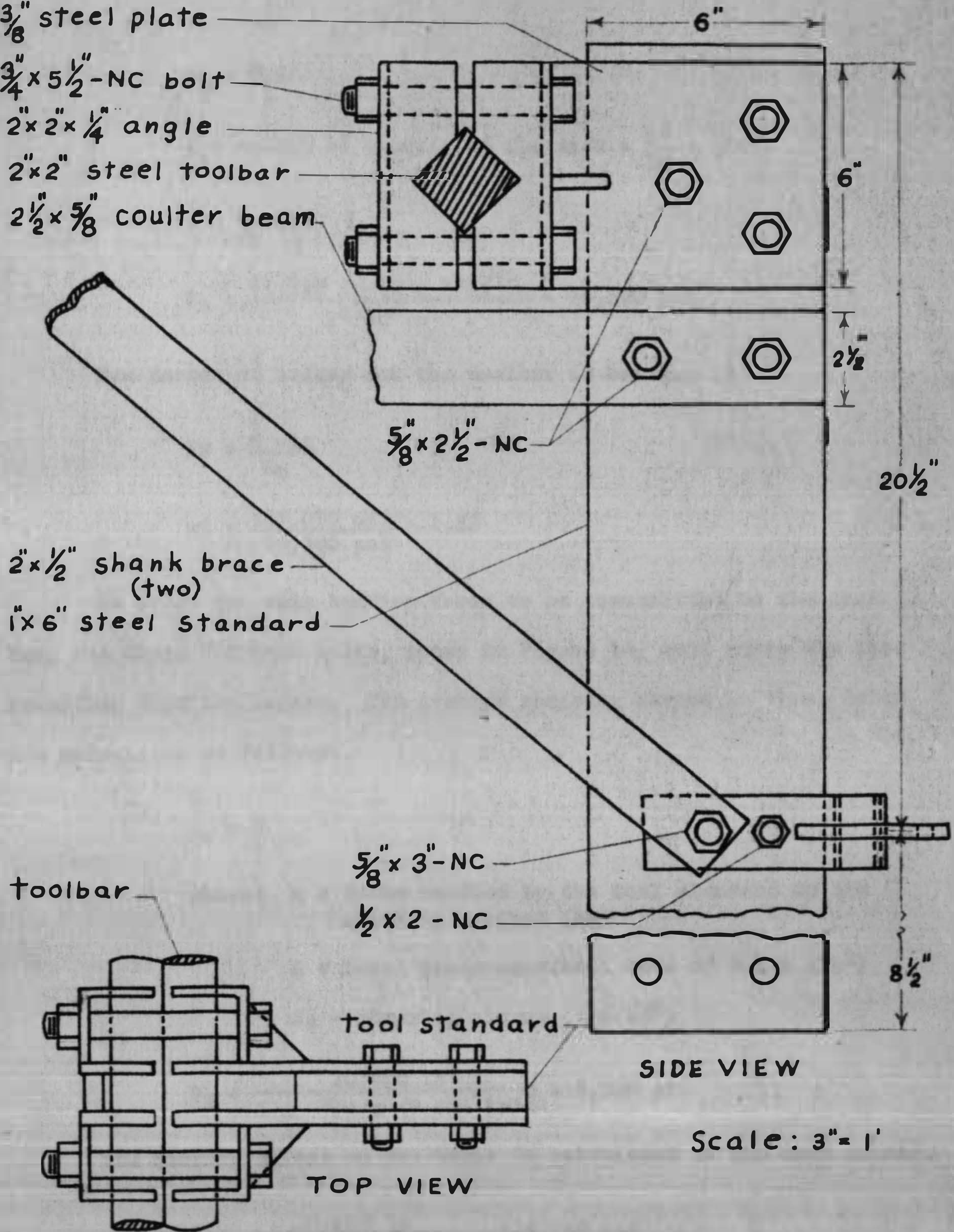


Figure 14. Tool Standard, Toolbar Mounting Bracket and Tool Standard Brace

$$S_b = \frac{M\,c}{I}$$

I = moment of inertia of the area = $\frac{b^4}{12}$ = (in^4)

$$c = \frac{d}{\sqrt{2}} \text{ (in)}$$

$$S_b = \frac{71,120 \text{ in-lb} \times 2/\sqrt{2} \text{ in}}{2^4/12 \text{ in}^4} = 75,500 \text{ psi}$$

The factor of safety for the toolbar in bending is

$$FS = \frac{S\ ult}{S_b}$$

$$FS = \frac{100,000 \text{ psi}}{75,500 \text{ psi}} = 1.33$$

In order for this bending force to be transmitted to the toolbar, the three 5/8 inch bolts, shown in Figure 14, must carry the load resulting from the impact. The average shearing stress in these bolts are calculated as follows:

$$S_s = \frac{R}{A}$$

where: R = force exerted by the tool standard on the mounting bracket (lb)

A = total cross-sectional area of bolts (in^2)

S_s = shearing stress (lbs/in^2)

$$S_s = \frac{10,900 \text{ lb}}{6 \times \pi/4 \times (0.625 \text{ in})^2} = 5,920 \text{ psi}$$

The bearing stress on the bolts is calculated in the same manner.

$$S = \frac{10,900 \text{ lb}}{6 \times 3/8 \text{ in} \times 5/8 \text{ in}} = 7,750 \text{ psi}$$

Since in this instance the shearing stress is of greater significance, the factor of safety for the bolted connection is

$$FS = \frac{S_s\ ult}{S_s}$$

$$FS = \frac{44{,}000\ psi}{5{,}920\ psi} = 7.43$$

The tool standard braces are designed to stabilize the tool standard and transmit much of the force, acting upon the V-blade, to the tool carrier. These braces also eliminate torsion stresses in the toolbar.

The standard braces consist of two 2 x 1/2 inch steel bars as shown in Figure 14. These braces are fastened to the tool standard with a 5/8 inch bolt. A 3/4 inch steel rod is welded to the upper end of each brace as shown in Figure 15. These rods are threaded so the braces can be placed in initial tension. Lateral adjustment in the tool standard is made on the threaded portion of the braces.

Figure 15 also shows the bracket used in attaching the standard braces to the tool carrier frame. The type of bracket employed will depend upon the particular tool carrier on which the contour furrower is mounted.

The tension in each brace resulting from an impact load of 8,000 pounds was previously calculated on page 41. Stress in the 3/4 inch threaded rod is

$$S = \frac{T_L}{A}$$

where, T_L = tension in the left brace (lb)

A = stress area of a 3/4-NC bolt (in^2)

$$S = \frac{8{,}800\ lb}{0.334\ in^2} = 26{,}350\ psi$$

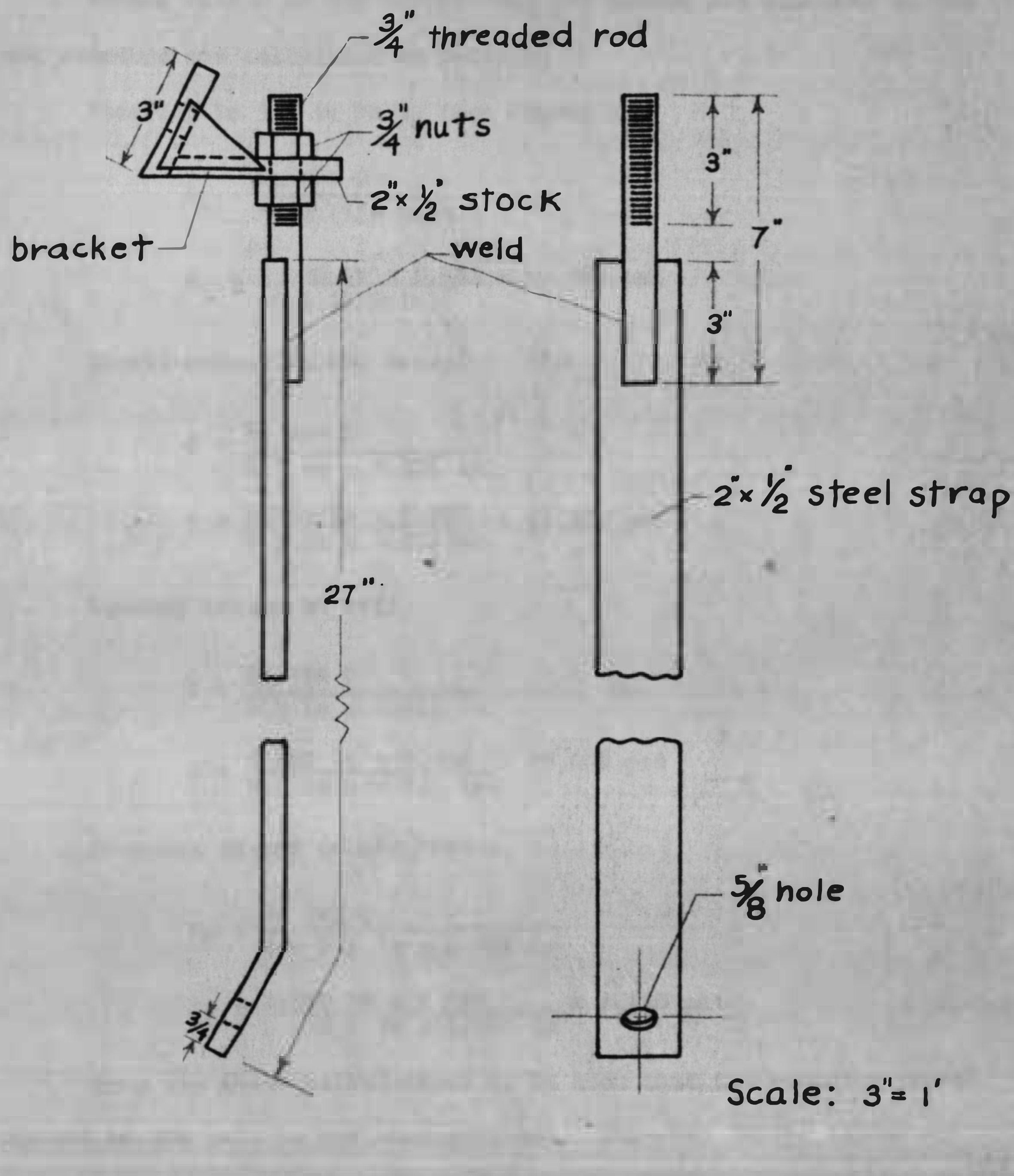


Figure 15. Tool Standard Brace and Attachment Bracket

Stress values at the point where the braces are attached to the tool standard are calculated as follows:

Shearing in 5/8 in bolt, (see Figure 15),

$$S_s = \frac{T_L \cos \phi}{\pi/4\ (5/8\ \text{in})^2}$$

$$S_s = \frac{8{,}800\ \text{lb} \times 0.888}{\pi/4\ (5/8\ \text{in})^2} = 25{,}500\ \text{psi}$$

Tensil stress in the brace,

$$S = \frac{T_L \cos \phi}{0.5\ \text{in} \times 1.375\ \text{in}}$$

$$S = \frac{8{,}800\ \text{lb} \times 0.888}{0.5\ \text{in} \times 1.375\ \text{in}} = 11{,}370\ \text{psi}$$

Bearing stress on bolt,

$$S = \frac{T_L \cos \phi}{0.5\ \text{in} \times 0.625\ \text{in}}$$

$$S = \frac{8{,}800\ \text{lb} \times 0.888}{0.5\ \text{in} \times 0.625\ \text{in}} = 25{,}000\ \text{psi}$$

Shearing stress in the brace,

$$S_s = \frac{T_L \cos \phi}{2 \times 0.5\ \text{in} \times 1.062\ \text{in}}$$

$$S_s = \frac{8{,}800\ \text{lb} \times 0.888}{2 \times 0.5\ \text{in} \times 1.062\ \text{in}} = 7{,}350\ \text{psi}$$

From the above calculations it is seen that the shearing stress exerted on the bolt is the most critical. Thus the factor of safety for the brace connections is

$$FS = \frac{S_s\ \text{ult}}{S_s}$$

$$FS = \frac{44{,}000\ \text{psi}}{25{,}500\ \text{psi}} = 1.73$$

Disk and Disk Beam Assembly

The function of the disk is to transfer soil from beneath the upper sod slice to beneath the lower sod slice. Transferred soil elevates the lower slice which forms a levee. In addition, the depression made by the disk permits the upper sod slice to be placed lower than its original position.

A disk was selected to perform this operation because of the desirable configuration of the resulting furrow. The furrow and ridge made by a disk have semicircular shapes. This is desirable since the sod slices are not curved abruptly when laid in place over the furrowed surface. In this way there is less tendency for the sod slices to be broken.

Since the disk must operate beneath the lifted sod, it is limited in size by the height to which the sod is lifted. The sod rack is designed to lift the sod slices without breaking them Thus, the disk and disk beam are designed to operate in the limited space beneath the sod rack.

The disk and disk journal used in this design are parts of a standard model lister planter manufactured by a major farm machinery company. Modifications were made by reversing the disk on the bearing in order to position the bearing on the convex side of the disk. The cast iron bearing was replaced with a steel bearing to provide greater strength and permit easier welding to the supporting member. Two disk scrapers were also welded to the disk bearing.

The disk and disk beam assembly is shown in Figure 16. All parts (except for the disk and disk journal) were constructed with commercially available steel stock.

A steel shaft 1-1/2 inches in diameter and 11 inches long was machined to 1 5/16 inches in diameter. The shaft was welded to the disk bearing and mounted inside a 1 1/2 inch pipe bearing. This provided disk angle adjustment at the outer end of the disk beam.

Two 1/4 inch steel plates were welded to the pipe bearing to strengthen the disk assembly and to provide a simple means of attaching the disk assembly to the beam.

The disk assembly is held in place on the disk beam with two 1/2 inch bolts as illustrated in Figure 16. Disk tilt angle adjustments from 20 to 25 degrees, are made by loosening the upper bolt and retightening it in the desired position within the slotted hole.

Cold rolled steel was used in the construction of the disk beam. A one inch diameter shaft was welded to the beam and supported vertically by two one inch thick-walled pipe bearings. This permits the disk beam to be swung horizontally in order to position the disk beneath the left or right section of the sod rack. The relative location of the disk and disk beam assembly is shown in Figure 17.

One of the important objectives in the design of this machine was to provide a satisfactory means of making disk angle and disk beam adjustments. This was accomplished by mounting two quadrant hand levers on the tool carrier frame. Levers used in this machine were taken from an old row-crop cultivator. However, other levers of this type would be suitable.

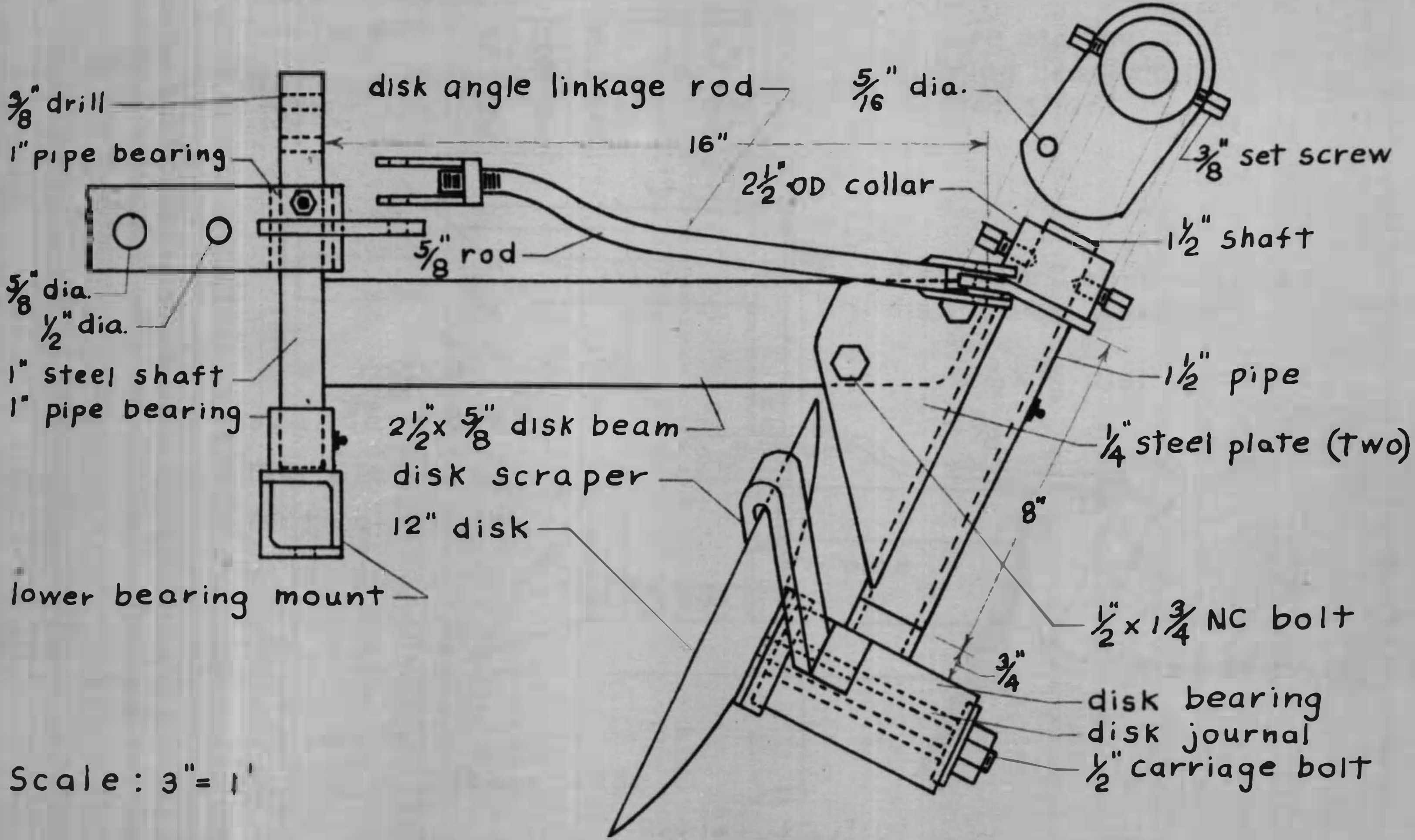


Figure 16. Disk and Disk Beam Assembly

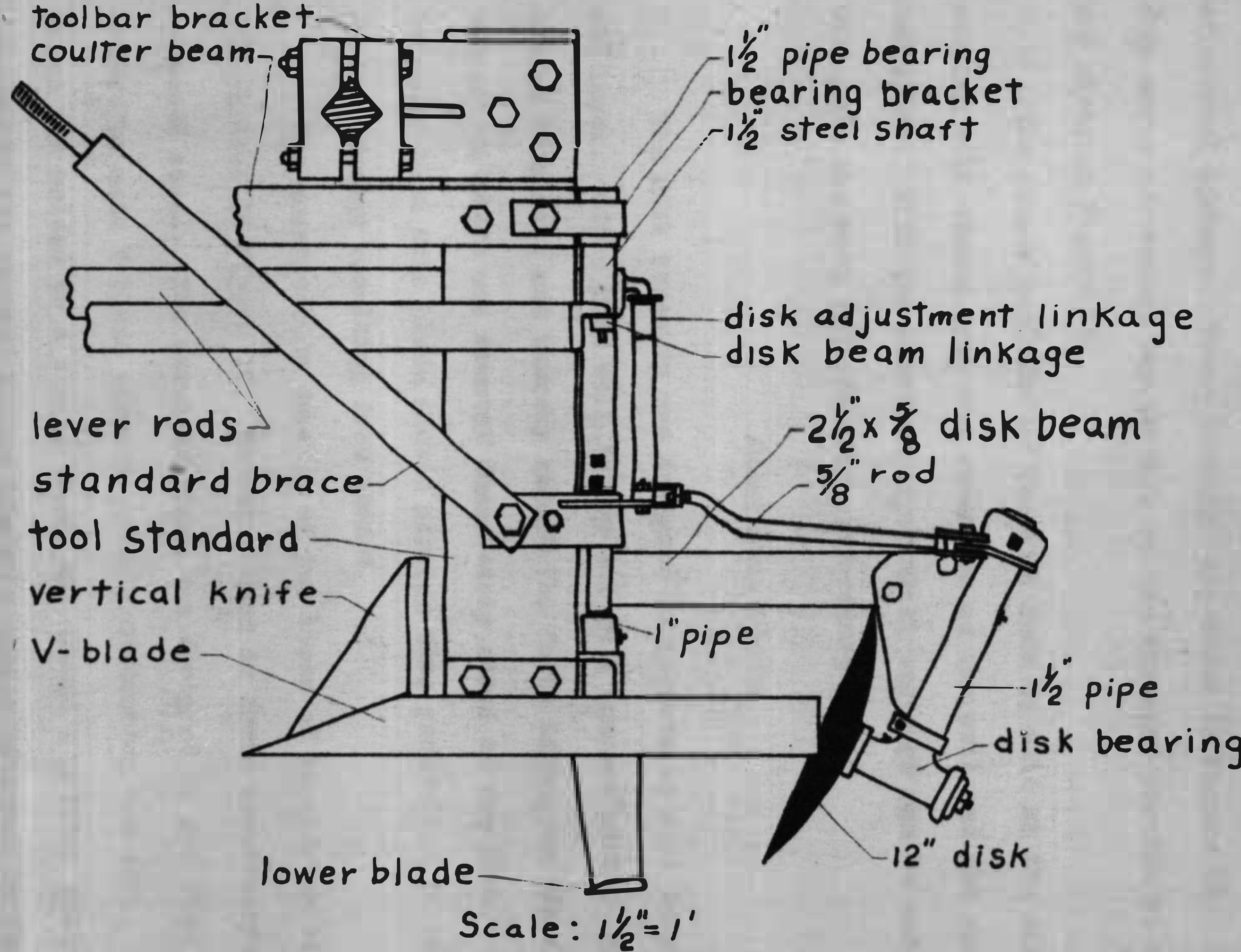


Figure 17. Side View of Pasture Contour Furrower Showing the Disk and Disk Beam Assembly

Lever rods connect the levers to the disk angle and disk beam adjustment linkage. These linkages are shown in Figure 18. Additional disk angle adjustment may be made on the threaded portion of the linkage rod shown in Figure 16.

The proper position of the disk beam as well as the disk angle setting will depend upon the condition of the soil and the speed of operation. With the provided adjustment, settings can be made which will give the most satisfactory performance.

Scarifying Blades

The disk assembly was designed to operate in soil beneath the sod layer. Often this soil is dry and in a compact state. In order to loosen this soil and thereby reduce the force acting on the disk, a scarifying blade was mounted immediately ahead of the disk. It was also intended that this blade should provide some protection to the disk against damage resulting from stones.

The construction details of two types of scarifying blades are illustrated in Figure 19. Material used in their construction was hardened steel. The straight blade was designed to cut five inches below the main V-blade without greatly disturbing the soil. The other blade was welded to a single shank and caused a greater soil disturbance because of its shape. Either blade is easily attached to the furrower with two 1/2 inch bolts. Figure 20 shows the two blades mounted on the main furrowing tool.

It was expected that the draft requirements of the machine would be slightly increased by the scarifying blades. Of greater concern,

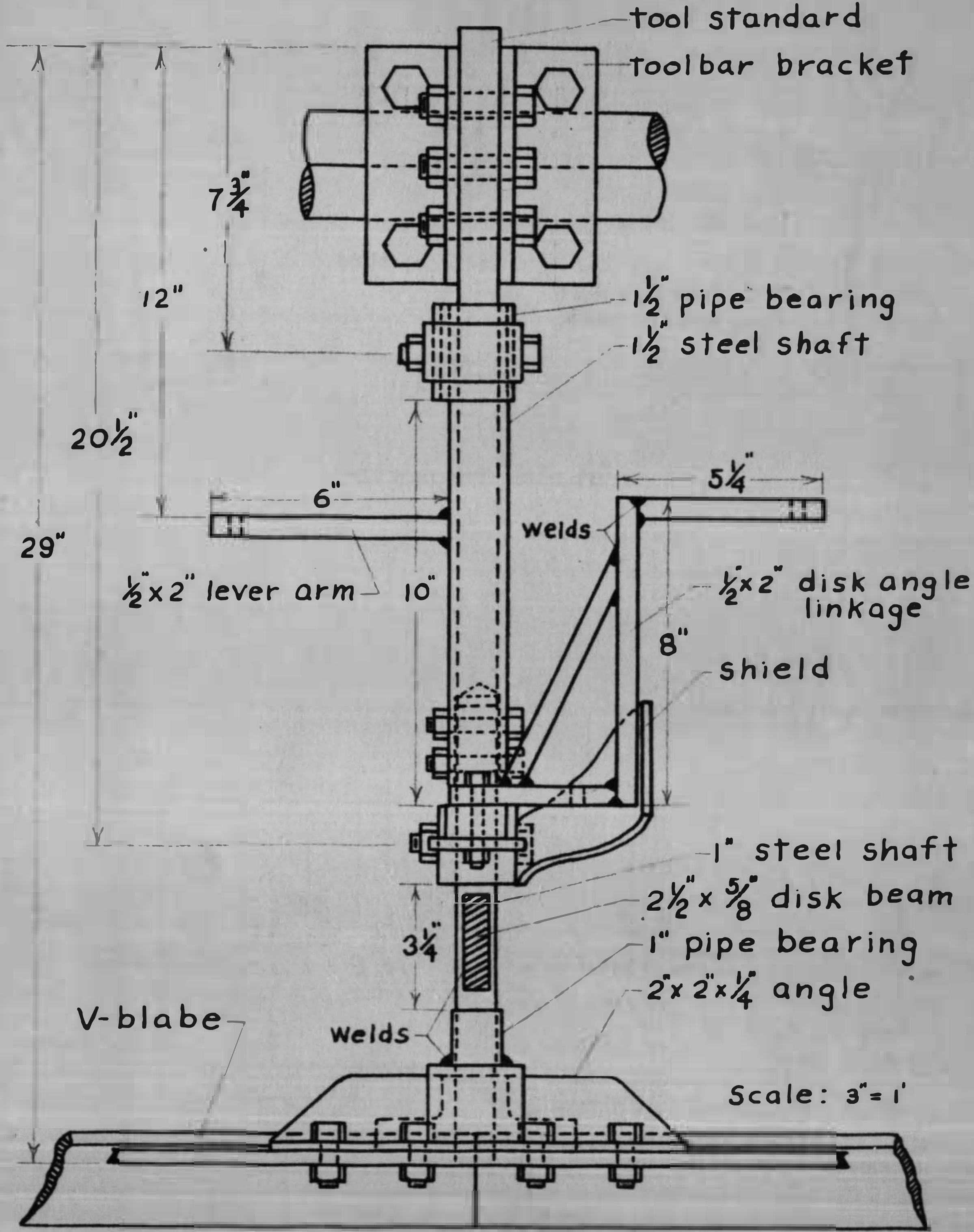


Figure 18. Rear View of the Tool Standard Showing the Disk Beam and Disk Angle Adjustment Linkage. (The Tool Standard Braces are not shown.)

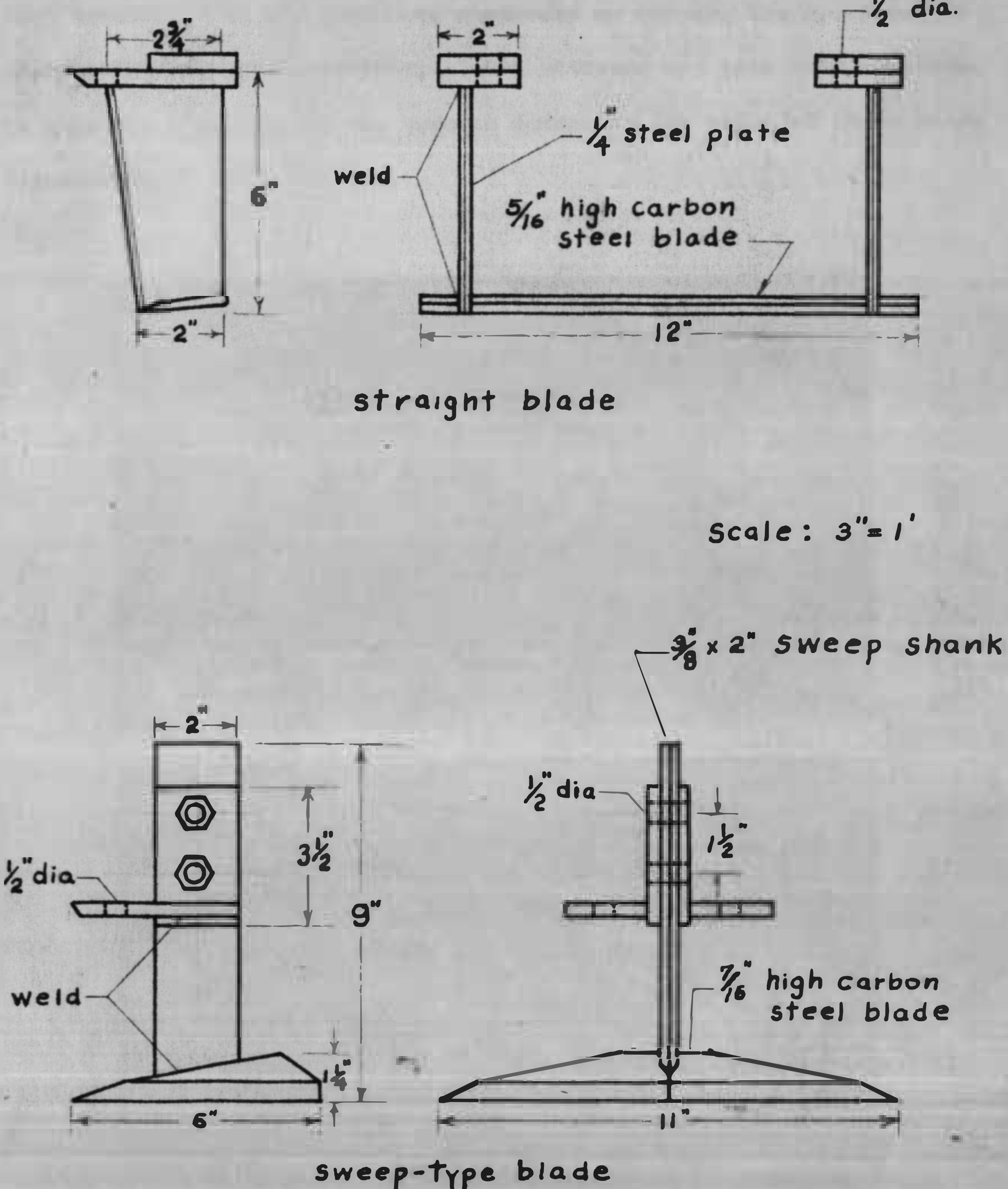


Figure 19. Scarifying Blades

however, was their effect on the performance of the main V-blade and disk assembly. It was therefore necessary to observe the operation of the machine with the scarifying blades attached and with them removed. In this way a comparison was made to determine the value of these blade attachments.

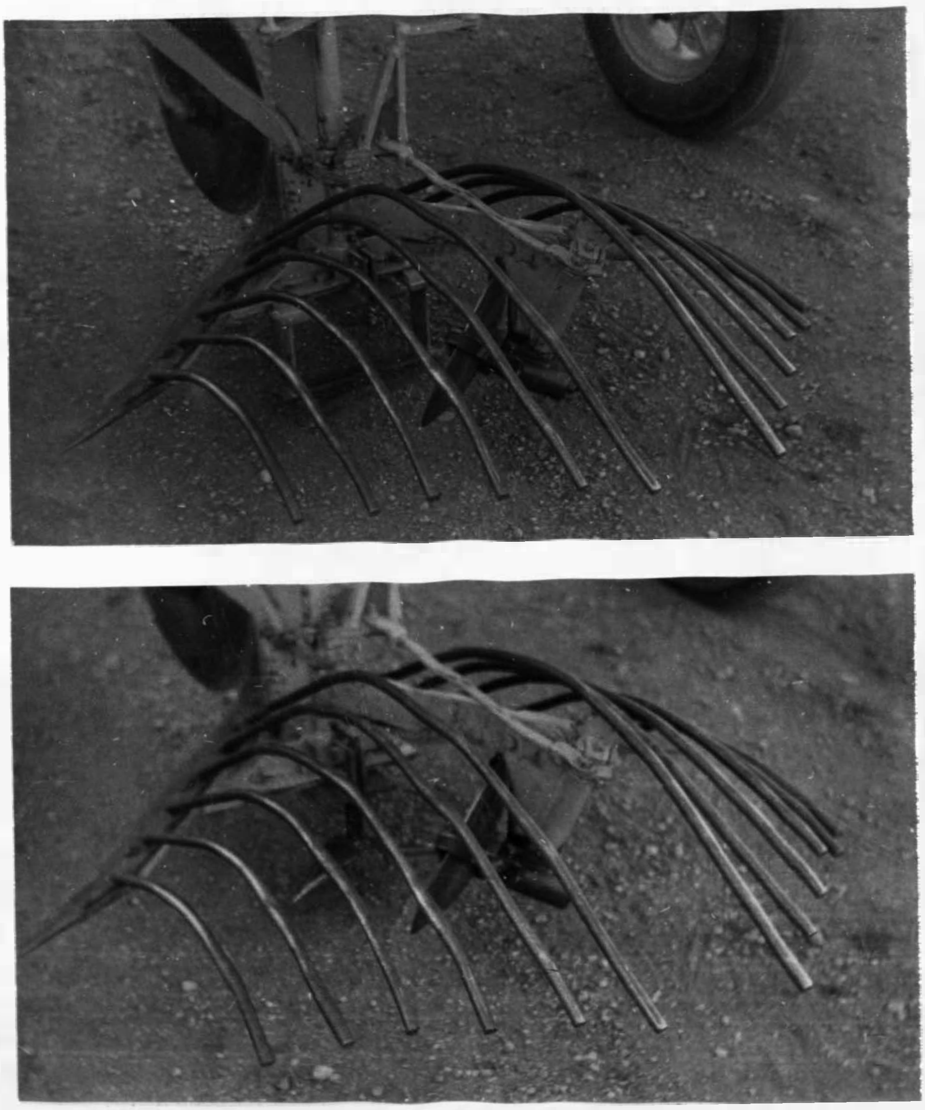


Figure 20. Straight and Sweep Type
Scarifying Blades Attached
to the Furrower

FIELD TESTS

Preliminary field tests were conducted with the furrowing machine in June, 1960, on the Agricultural Engineering Experimental Farm, Brookings, South Dakota. The purpose of these tests was to observe the general characteristics of operation in order that the necessary changes in design could be made before undertaking more extensive tests. This test area was located on low, level land along the Big Sioux River where soil moisture conditions were quite high. Soil in this area was a fine textured clay and was free of stones. Since the land had not been grazed, the grass cover was extremely dense and tall.

Tests revealed that additional weight was needed to initially force the V-blade through the dense upper layer of sod. Without the added weight, the upward force exerted by the disk prevented the V-blade from entering the soil. However, after the V-blade had once entered the soil, suction forces appeared to overcome the lifting effect of the disk.

The disk's performance was quite satisfactory even though the soil was wet and sticky. Rotation of the disk was somewhat restricted by its inability to scour. Nevertheless, proper functioning was made possible by the cleaning action of the disk scrapers. The high moisture conditions also made it necessary to set the disk at a smaller angle than would be used under more favorable conditions.

During these preliminary tests, the V-blade was operated three to four inches below the soil surface. The sod slices were not broken, but they appeared to be held back by the disk angle and disk beam linkages. Since this interference occurred quite frequently, it was decided that the linkage should be raised to provide additional clearance for the sod slices.

The scarifying blades did not properly function in this test area. With the blades mounted, the sticky soil clogged beneath the V-blade lifting the entire furrower out of the ground. It was also noted that the draft requirement of the machine was markedly increased by the scarifying blades. This was attributed to the high soil moisture condition and subsequent build-up of soil beneath the V-blade.

Soil moisture and grass cover conditions in this test area were not representative of pastures where contour furrows would be beneficial. However, these preliminary tests pointed out various needed improvements which were made before testing was continued.

The test area was examined a week after the preliminary field tests were conducted. Grass covering the sod strips had continued to grow and appeared to have been only slightly retarded by the furrowing operation. It was also noted that the furrow ridge had settled about one inch during this period. The sod slice covering the depression had also settled making good contact with the underlying soil. Measurements were not made of the finished furrow because the soil moisture and grass cover conditions were not considered typical of sloping pastures.

Field testing was resumed in July on a native grass pasture near Brookings, South Dakota. Although in need of moisture, the test area had a good cover of mid grass and had been lightly grazed. The soil was of a loam texture and contained a few scattered stones throughout the profile. Due to the lack of moisture, the ground surface was quite hard.

In this test, furrows were constructed on a level contour and were spaced ten feet apart. The test was conducted on land with an eight per cent slope which provided ideal conditions for observing the furrower's operation on hilly pasture.

This field test also revealed that added weight was needed to force the V-blade into the ground. The weight was added by placing five 100 pound bags of sand in the weight box located on the tool carrier. The additional weight was also needed to maintain uniform depth control and prevent the furrower from coming out of the ground.

The pasture furrower was pulled with a 1957 model three-plow tractor. While second gear was generally adequate, it was occasionally necessary to use first gear. Considerable slippage of the tractor's rear wheels was also noted during this field test. Under these conditions it was felt that a four-plow tractor would have been more suitable.

Although the soil was too dry for the furrowing operation, the sod rack complied reasonably well with its requirements. However, the sod slices did crack and break as they passed over the highest point of the sod rack. By cutting thin sod slices, this breaking was reduced but not eliminated. Further observation revealed that an improvement could be made by decreasing the curvature of the sod rack. This was accomplished by bending the rods upward and raising the rear of the rack.

Operating the furrower without the rolling coulter was not very successful. Although the overall performance of the machine was not greatly affected, the cut edges of the sod slice were rough and uneven. To evenly separate the sod slice, it was found that the coulter need only cut two inches below the ground surface. The general appearance of the furrow was greatly improved when the coulter was employed.

Particular notice was taken of the disk's operation during this test. When compared to the preliminary test, the disk functioned extremely well. This improved operation is attributed to the fact that the dry soil presented very little scouring resistance as did the wet soil. It was also noted that the disk could be operated at a greater disk angle in the dry soil. This, of course, increased the amount of soil shifted by the disk.

Various disk angle settings were made in an attempt to determine the most effective setting. Observations revealed that settings between 45 and 60 degrees could be used satisfactorily. The best setting will depend upon the speed of operation and the characteristics of the soil.

The disk beam was adjusted and operated at about 20 degrees from its centered position. As with the disk angle, the proper setting of the disk beam will depend upon operating conditions. All disk angle and disk beam adjustments were conveniently made with the hand levers. However, no attempt was made in making adjustments while the machine was in motion because of the force exerted on the disk beam and its adjustment linkage.

Each scarifying blade was mounted on the machine for a trial run. Both blades increased the draft of the furrower to the point where the tractor's wheels slipped excessively. With the straight scarifying blade mounted, difficulty was expreienced in forcing the V-blade into the hard, dry soil. This was caused by sod lodging between the scarifying blade and the disk. The sweep-type scarifying blade was less troublesome in this respect; however, poor penetration of the furrower was also evident. Further testing of these blade attachments was discontinued because of their interference with the overall operation of the furrower.

In order to insure the continued growth of grass on the sod slices, it is recommended that furrows be constructed when soil moisture is relatively high. Pasture furrows are usually constructed in the early spring or late fall. Spring and early summer furrowing should also be successful if the work is done during or immediately following a rainy period.

Field tests were continued late in July even though pastures in this area were extremely dry. A closely grazed bluegrass pasture was selected as the test site. Soil in this pasture was a fine textured clay, possessing good granular structure. Since the land was undulating, furrows were constructed on 5, 10, and 20 per cent slopes.

Part of these tests were conducted for the purpose of obtaining draft requirement data. Earlier field tests had revealed that a three-plow tractor was occasionally inadequate. A five-plow tractor was, therefore, employed in order that sufficient power would be available for making draft measurements.

An electrical-resistance strain-gage transducer was specially designed and used for measuring the draft requirement of the pasture furrower. The transducer was bolted between the tractor drawbar and the tool carrier. Lead wires from the strain gages were connected to an amplifier equipped with an indicating meter. This instrument was calibrated to indicate draft directly in pounds. Figure 21 shows the transducer and amplifier mounted on the tractor drawbar.

Draft measurements were made with the V-blade cutting four inches below the soil surface and the tractor operating at a speed of three miles per hour. Throughout these draft tests an effort was put forth to maintain constant depth and speed conditions. The primary objectives of these tests were to measure the average total draft requirement of the furrower and also measure the draft contributed by the V-blade, disk assembly, sod rack, and scarifying blades.

During these tests considerable meter fluctuation made it necessary to estimate the average draft readings. The first draft readings were made with the furrow completely assembled except for the scarifying blades. In the second test, however, the sweep-type scarifying blade was attached in order to determine the increased draft resulting from its presence. The third test was conducted with the scarifying blade and disk assembly removed. For the final test, the sod rack was removed leaving only the V-blade remaining. A summary of the average draft for each test is shown in Table III.

From Table III it can be seen that the total draft of the furrower was greatly increased by the scarifying blade. An investigation revealed that the free movement of soil over this scarifying blade and around its shank was restricted by the upper base plate of the main V-blade. This interference could probably be eliminated by mounting the scarifying

Figure 21. Strain-Gage Transducer and Amplifier Mounted on the Tractor Drawbar

TABLE III. AVERAGE DRAFT REQUIREMENTS OF THE VARIOUS COMPONENTS OF THE PASTURE FURROWER

Draft Test	Condition of Furrower During the Test	Average Draft Pounds
1	Completely assembled without scarifying blade	3,200
2	Completely assembled with scarifying blade*	4,900
3	V-blade and sod rack	3,000
4	V-blade alone	2,900

*The sweep-type scarifying blade

blade further back. However, the limited space between the base plate and the disk made such a change impossible.

The draft tests also showed that the disk and sod rack contributed very little to the total draft of the machine. Since the draft varied considerably within each test, it was difficult to evaluate all the possible influencing factors.

Figure 22 shows the pasture furrower in operation on a well-sodded bluegrass pasture. The sod slices did not crack or break during the furrow construction even though the soil was very dry. When compared to the test made earlier on a native grass pasture, this improved operation was probably due to soil differences rather than the reduced curviture of the sod rack.

The general appearance of the finished furrow is shown in Figure 23. This furrow was made on a ten per cent slope with the V-blade cutting four inches below the surface. Without being packed, the sod slices settled into place under their own weight.

It appeared that the finished furrow could be made more stable by packing the sod slices. Thus, some of the furrows were packed with a rear wheel of the tractor while others were packed by running two wheels of a pickup truck in the furrow. Figure 24 shows a cross section of a furrow after having been packed with the rear wheel of the tractor. The added expense and necessity of making an extra trip to pack the furrows could be eliminated by hitching and pulling a heavy roller directly behind the pasture furrower. It would be most desirable if a packer or roller was specially built to conform to the contour of the furrow.

Figure 22. Pasture Furrower in Operation

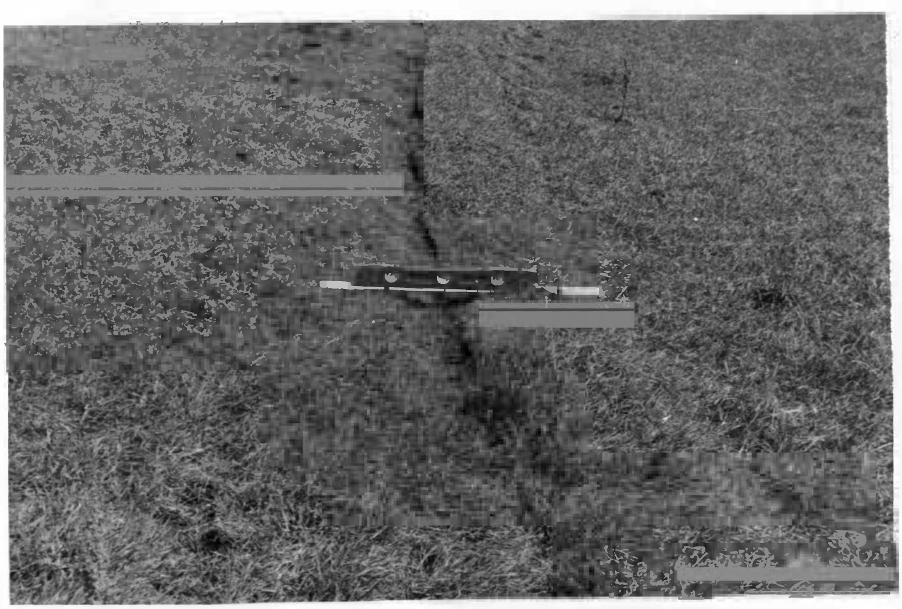


Figure 23. General View of the Finished Furrow

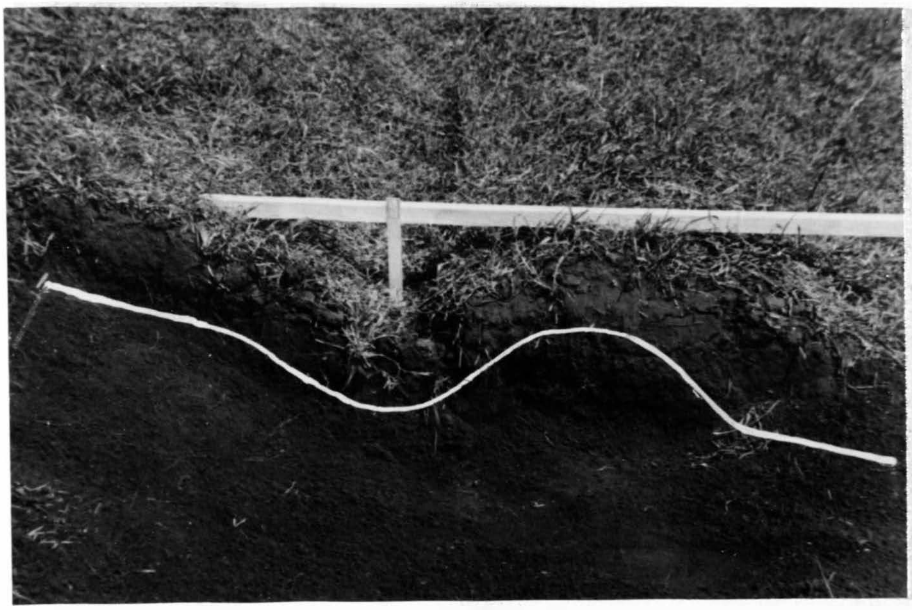


Figure 24. Cross Section of the Finished Furrow Constructed on a 20 Per Cent Slope. (The line denotes the lower surface of the sod slice.)

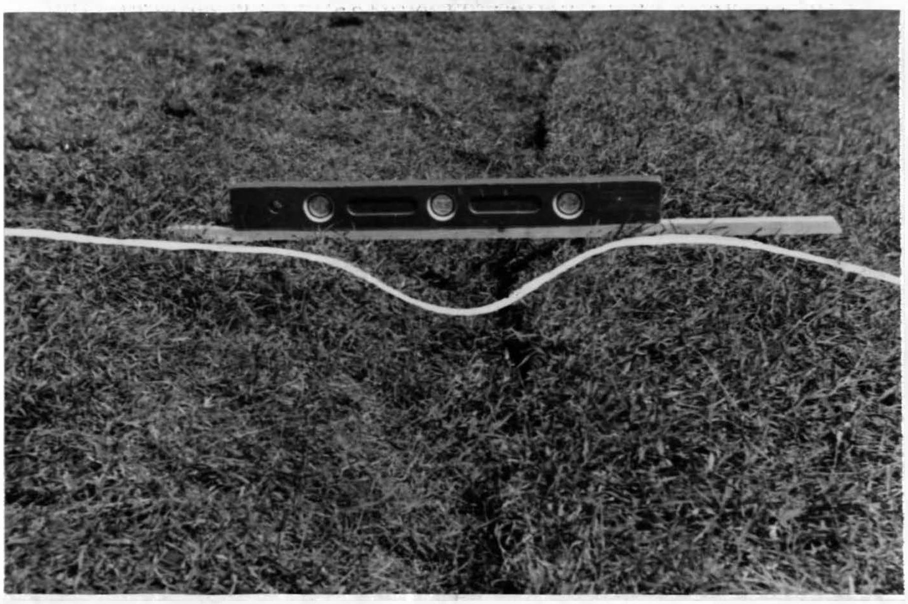


Figure 25. The Finished Furrow Constructed on a 10 Per Cent Slope. (The line illustrates the space available for water detention.

Two weeks after the above furrows were constructed, the test area was examined. The original configuration of the furrows was retained although some settling of the sod slices was noted. Most of the grass covering the sod slices was dead due primarily to lack of precipitation both before and after the furrows were constructed.

The water storage potential of these furrows, assuming non-infiltration, is dependent upon these three factors: the slope of the land, the size of the depression and the effective height of the levee. Measurements were made of the furrows in order to determine their approximate retention capacities under various conditions. Figure 25 illustrates the depth to which water will be stored in a furrow constructed on a ten per cent slope. The average effective height of the settled furrow levee was three inches above the original ground surface. Measurements made of furrows constructed on level ground showed that the ridges were on the average five inches higher than the bottom of the furrow. The storage potential and recommended furrow spacings for storing various amounts of runoff are given in Table IV.

Furrow spacing intervals are generally selected by using pertinent rainfall data and estimating runoff conditions. The rainfall intensity in inches per hour for a two or five-year frequency storm is determined for the area to be furrowed. This value is then multiplied by an appropriate runoff coefficient to obtain the expected runoff in inches per hour. The proper layout of these contour furrows will greatly increase their effectiveness.

TABLE IV. THE CALCULATED STORAGE POTENTIAL* OF CONTOUR FURROWS AND FURROW SPACINGS REQUIRED FOR STORING VARIOUS AMOUNTS OF SURFACE RUNOFF

Slope Per Cent	Storage Potential Cu. Ft. per Ft. of Furrow	Furrow Spacing (in feet) Required to Store Runoff					
		0.25 in.	0.5 in.	0.75 in.	1.0 in.	1.25 in.	1.5 in.
1	1.90	57.3	28.7	19.1	14.4	11.5	9.6
2	1.02	49.0	24.5	16.3	12.3	9.8	8.2
3	0.92	44.0	22.0	14.7	11.0	8.8	7.3
4	0.68	32.7	16.3	10.9	8.2	6.5	5.5
5	0.61	29.2	14.6	9.7	7.3	5.8	4.9
6	0.46	22.0	11.0	7.4	5.5	4.4	--
7	0.43	20.5	10.3	6.8	5.1	4.1	--
8	0.40	18.7	9.3	6.2	4.7	--	--
9	0.35	16.7	8.3	5.6	4.2	--	--
10	0.31	14.8	7.4	5.0	--	--	--
11	0.28	13.5	6.8	4.5	--	--	--
12	0.26	12.3	6.1	4.1	--	--	--
13	0.22	10.4	5.2	--	--	--	--
14	0.21	9.9	5.0	--	--	--	--
15	0.20	9.5	4.7	--	--	--	--
16	0.19	9.0	4.5	--	--	--	--
17	0.18	8.5	4.3	--	--	--	--
18	0.17	8.0	4.0	--	--	--	--
19	0.16	7.6	--	--	--	--	--
20	0.15	7.1	--	--	--	--	--

*Table was calculated from the measured furrow cross section and is based on nonfiltration.

SUMMARY

A pasture furrower machine that will construct contour furrows without destroying the protective sod mantle was designed and tested. Design criteria for this machine were obtained from a study of the present trends and needs of the pasture furrowing practice in South Dakota. This study also revealed that the implements frequently employed, construct contour furrows with many undesirable characteristics. The destruction of considerable sod and exposure of the underlying soil were common objections.

The pasture furrower described in this thesis consists of a two-way furrowing tool mounted on a conventional tool carrier. A rigid and well braced tool standard supports the furrowing tool which is composed of a V-shaped blade, sod rack and disk assembly. Provisions are made in order that the operator may reverse and adjust the working angle of the disk without having to dismount from the tractor.

The furrow is formed by cutting and lifting two sod slices while the disk, fastened immediately behind the V-blade, removes soil from under the upper sod slice and throws it beneath the lower slice. As the disk shifts the underlying soil, the sod slices progress over a curved rack and are lowered over the newly formed surface. Thus, protection against sloughing and erosion is afforded this type of furrow.

Field tests conducted with this machine showed that the average effective height of the finished furrow levee was 3 inches above ground level and 5 inches higher than the bottom of the depression. The measured cross sections of furrows constructed on varied slopes were used to

calculate the furrows' storage potential. Tests were also conducted in an effort to determine the total draft requirement of the pasture furrower. It was revealed that a tractive effort of approximately 3,200 pounds was required to pull the furrower in a well-sodded pasture.

This machine has been successfully used to construct pasture contour furrows under varying slopes, grass cover and soil moisture conditions. These experiments have indicated that in order to insure continued growth of grass on the furrowed surface and improve furrower operation, this machine should be employed when soil moisture conditions are relatively high.

CONCLUSIONS

1. The pasture furrower developed in this study has been successfully used on native and bluegrass pastures in South Dakota. Furrows constructed with this machine have the following advantages over furrows made with moldboard plows and other field cultivation implements.
   a. Sod is not destroyed during furrow construction but is replaced over the furrowed surface.
   b. Soil is not exposed or scattered over the area between the furrows promoting weed growth.
   c. Furrows are more resistant to the destructive forces of wind and water erosion and are, therefore, more permanent.
   d. The curved surface of the furrow levee and depression provides less tendency for sloughing.
   e. Furrows can be more easily crossed by livestock and motor vehicles.
   f. With adequate soil moisture, grass covering the furrowed surface will continue to grow.
2. This pasture furrower is reasonably simple and can be constructed from readily obtainable materials.
3. The furrower can be easily mounted on most conventional trailed tool carriers.
4. A three-plow tractor may be used to pull this pasture furrower, however, a four-plow tractor is recommended since greater traction is generally available.

5. Upon settling, the average effective height of the furrow levee is three inches with the levee being five inches above the furrow bottom.
6. The most suitable time for constructing pasture contour furrows with this machine is when soil moisture conditions are relatively high.
7. For best results the sod slices should be brought into closer contact with the underlying soil. A heavy packer or roller which can be trailed behind the machine should be designed for this purpose.
8. In order to further develop this pasture furrowing machine, more extensive research is needed to determine the relative effects of soil variables and design features on its overall operation.

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