Tests of the effect of rotor size and reversible feature on the performance of a whirlwind type terracer

Everett Martin Sandahl

Iowa State College

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TESTS OF THE EFFECT OF ROTOR SIZE AND REVERSIBLE FEATURE ON THE PERFORMANCE OF A WHIRLWIND TYPE TERRACER

by

Everett Martin Sandahl

A Thesis Submitted to the Graduate Faculty in Partial Fulfillment of The Requirements for the Degree of MASTER OF SCIENCE

Major Subject: Agricultural Engineering

Signatures have been redacted for privacy

Iowa State College 1953
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INTRODUCTION

What Is Soil Conservation?

Soil conservation is the proper use and care of the land. It means using the land to produce the greatest amounts of adapted crops while at the same time protecting the land so that it will not lose its productiveness. Soil conservation is one of the youngest of the agricultural sciences and one of the most exacting. Real permanent conservation must be well planned and executed in accordance with sound scientific principles. At the same time it must be reduced to simple practical terms and methods so that the farmers who will work the land may understand it and use it as a part of their regular farming operations.

The program of soil and water conservation is necessarily large due to the hundreds of thousands of acres and the thousands of owners with which the agency must deal. The question then arises as to what would be the best method to accomplish the logical use of soil and water resources. Secretary of Agriculture Brannan mentions three possible steps:

1. Change our idea of land ownership of fee simple to the motto of the National
Association of Soil Conservation Districts, "with the right to own goes the duty to conserve".

2. Develop the science of proper land use.

3. Apply the coordinated science to every acre in America. (6, p. 17)
REVIEWS OF LITERATURE

The Soil Conservation District: Organization and Growth

Today this coordinated science of conservation is being applied to some 2255 conservation districts. Rapid growth of districts can best be noted in Table 1 and Figure 1. Progress in organizing the soil conservation districts was very rapid considering that the United States Congress established the Soil Conservation Service as a permanent agency of the Department of Agriculture in April of 1935. The President of the United States, then in turn, proposed to the governors of each state the adoption of the Soil Conservation Districts Law with a suggested outline on the procedure of organizing soil conservation districts as governmental subdivisions of the states. This legislation has now been enacted in all of the states, and in Puerto Rico, Virgin Islands, Hawaii, and Alaska.

The first Soil Conservation District to be set up was the Brown Creek District in North Carolina, August 4, 1937. Since the organization of the Brown Creek District, it is interesting to note in Table 2 that 35 million acres or 75 per cent of the total farm land within the Continental United States has been organized into Soil Conservation
<table>
<thead>
<tr>
<th>Calendar Year</th>
<th>Districts Organized</th>
<th>Total Area in Districts (acres)</th>
<th>Cumulative Total</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>New</td>
<td>Total</td>
<td>New and Additions to old</td>
</tr>
<tr>
<td>1937</td>
<td>13</td>
<td>13</td>
<td>8,002,022</td>
</tr>
<tr>
<td>1938</td>
<td>96</td>
<td>109</td>
<td>51,037,951</td>
</tr>
<tr>
<td>1939</td>
<td>108</td>
<td>217</td>
<td>60,450,905</td>
</tr>
<tr>
<td>1940</td>
<td>212</td>
<td>429</td>
<td>147,584,445</td>
</tr>
<tr>
<td>1941</td>
<td>224</td>
<td>653</td>
<td>115,553,677</td>
</tr>
<tr>
<td>1942</td>
<td>173</td>
<td>826</td>
<td>96,500,000</td>
</tr>
<tr>
<td>1943</td>
<td>177</td>
<td>1003</td>
<td>86,750,000</td>
</tr>
<tr>
<td>1944</td>
<td>218</td>
<td>1221</td>
<td>109,298,084</td>
</tr>
<tr>
<td>1945</td>
<td>240</td>
<td>1461</td>
<td>126,539,434</td>
</tr>
<tr>
<td>1946</td>
<td>294</td>
<td>1755</td>
<td>143,216,060</td>
</tr>
<tr>
<td>1947</td>
<td>84</td>
<td>1839</td>
<td></td>
</tr>
<tr>
<td>1948</td>
<td>170</td>
<td>2009</td>
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Table 1. (Continued)

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<thead>
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<th>Calendar Year</th>
<th>Districts Organized</th>
<th>Total Area in Districts</th>
<th>Farmers and Ranchers</th>
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<tr>
<td></td>
<td>Annually New</td>
<td>New and Additions to old (acres)</td>
<td>Total</td>
</tr>
<tr>
<td>1949</td>
<td>136</td>
<td>2145</td>
<td></td>
</tr>
<tr>
<td>1950</td>
<td>110</td>
<td>2255</td>
<td></td>
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</tbody>
</table>

Note: Totals at the end of each year are net, including corrections and adjustments made during the year. Figures from Soil Conservation Service Office, Ames, Iowa.

Based on the 1940 census of agriculture with some local variations for districts in parts of counties or on a watershed basis.
Figure I. Annual Growth of the Soil Conservation Service (Cumulative).

<table>
<thead>
<tr>
<th>YEAR</th>
<th>MILLIONS OF ACRES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1938</td>
<td>5</td>
</tr>
<tr>
<td>1939</td>
<td>10</td>
</tr>
<tr>
<td>1940</td>
<td>15</td>
</tr>
<tr>
<td>1941</td>
<td>20</td>
</tr>
<tr>
<td>1942</td>
<td>25</td>
</tr>
<tr>
<td>1943</td>
<td>30</td>
</tr>
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<td>1944</td>
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<tr>
<td>1949</td>
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<tr>
<td>1950</td>
<td></td>
</tr>
<tr>
<td>1951</td>
<td></td>
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Table 2.

Comparative Figures Showing the Total Number of Acres Within the United States and Iowa, and the Number of Acres Within Soil Conservation Districts as of January 1, 1951

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<tr>
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<th>United States</th>
<th>Iowa</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>(acres)</td>
<td>(acres)</td>
</tr>
<tr>
<td><strong>Total Area</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In States</td>
<td>1,905,322,880</td>
<td>35,830,400</td>
</tr>
<tr>
<td>In Soil Conservation Districts</td>
<td>1,271,759,971</td>
<td>34,170,206</td>
</tr>
<tr>
<td>Per Cent of Area in Soil Conservation Districts</td>
<td>66.7%</td>
<td>95.4%</td>
</tr>
<tr>
<td><strong>Total Farmland</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In States</td>
<td>1,141,613,510</td>
<td>34,453,936</td>
</tr>
<tr>
<td>In Soil Conservation Districts</td>
<td>855,894,388</td>
<td>34,170,206</td>
</tr>
<tr>
<td>Per Cent of Area in Soil Conservation Districts</td>
<td>75%</td>
<td>99.2%</td>
</tr>
<tr>
<td><strong>Total Farms</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In States</td>
<td>5,859,129</td>
<td>208,934</td>
</tr>
<tr>
<td>In Soil Conservation Districts</td>
<td>4,769,228</td>
<td>207,191</td>
</tr>
<tr>
<td>Per Cent of Area in Soil Conservation Districts</td>
<td>81.4%</td>
<td>99.2%</td>
</tr>
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*Figures from the Soil Conservation Office, Ames, Iowa.*
Districts. This farm land represents 81.4 per cent of the total number of farms in the United States. It is also interesting to note the relatively high percentage of farm land in Iowa which has been organized within the soil conservation districts.

Figure 1 shows the number of acres which have a soil conservation program planned and the number of acres in which the soil conservation program is actually in practice. It is interesting to compare the figures for 1950 which show 39 million acres having a soil conservation plan, as against 27 million acres on which the soil conservation plan has been put into practice. Of the 856 million acres within organized soil conservation districts, only 27 million acres, or slightly more than 3 per cent, now have the soil conservation program in practice. This leaves almost 97 per cent of the land organized in soil conservation districts yet to be planned and the resulting soil conservation plan to be put into practice. These figures shed some light on the importance of the job yet to be done by the Soil Conservation Service.

As for continued need for this conservation science, Brannan says,

"The diminishing quantity and quality of our land and forests, the growing importance of food in world affairs and the increasing requirements of our own population—all emphasize the need for a
national policy and plan for the most effective utilization now and in the future of our limited agricultural resources. We must have a conservation program which will enable us to move as fast as possible toward a permanent agriculture. (6, p. 18)

Concerning the building of this "permanent agriculture", a few figures show that future food needs and available agricultural land are related factors. More pounds of the high protein foods such as meat, dairy products, vegetables, and fruit are consumed today than before World War II. A crop production from some 415 million acres as compared with some 406 million acres before World War II will be required to offset the increased per capita consumption for 142 million people. On top of this some experts have estimated that the United States will reach a peak population of 160 million to 170 million people by 1970.

To add to an already distressing condition, the Soil Conservation Service has estimated that some 61 million acres of steep eroded land now cropped should be sown to grass or planted to trees. Studies also show enough forest land available if well managed. However, 1944 figures show that only 164 million acres of the total 461 million acres in forest lands were under planned management. Figures show that our lumber is being consumed at a rate double the present annual growth. The situation on the range lands shows about 435 million acres are in satisfactory
condition while some 500 million acres have been impaired as a result of past abuse, present grazing practices, and fire.

On the favorable side of the ledger some 70 or 80 million acres of land may be used for crops by clearing and preparing land for irrigation. The cost of such operations would be high and undoubtedly will need considerable amounts of public funds.

Secretary of Agriculture Brannan comes to three conclusions about the formation of the "permanent agriculture". These conclusions are as follows:

The first major conclusion is that despite past misuse, we still have the physical resources with which to build a permanent agricultural plant adequate to meet the needs of our growing population for sustained agricultural abundance.

The second major conclusion is that if we are to achieve this goal of sustained agricultural abundance, we must as rapidly as possible and within the limits of economic feasibility apply the necessary measures to stop the further deterioration of our agricultural resources and restore the productivity of lands damaged by past abuse.

The third major conclusion is that as we go forward toward our goal we must make sure to tie down securely the gains that we make. Our margin will be too close to revert to former ways. (6, p. 19)

The importance of a good soil and water conservation program as part of a plan for a permanent agriculture can be clearly seen. Continued agricultural production requires conservation of our natural resources.
Economic Aspects of a Soil and Water Conservation Program

The economics of soil and water conservation is one of its most important phases. Economics will be the deciding factor in selling the program of soil and water conservation to the tenant, the land owner, and the public. The soil and water conservation program has three problem areas:

First, the issues faced by landlords and tenants in achieving profitable conservation programs; second, general principles an individual farmer should follow in making conservation investments; and third, public responsibilities where conservation is unprofitable for individual farmers. (17, p. 17)

Tenants generally make bad conservation farmers. The reason for this condition is that they usually are under a short term lease and would obtain little or no benefit from an investment in the conservation of soil and water.

A few figures may be interesting concerning investments in soil and water conservation and the probable annual return on such investments. If $1000 were invested today, it must return $1060 a year from now or $1123.60 in two years, considering a rate of six per cent compounded annually. Another example could be a $750.00 investment today must return $1100.00 in five years in order to interest the farmer in a program of soil and water conservation. The whole answer is that the program must pay as well as the average investment the farmer may make with his savings of today.
Along with the whole program of soil and water conservation, it must be recognized that there is a definite risk involved, just as in any other type of investment. Such troubles as terraces washing out, gullies forming due to high intensity rains, or seedlings failing due to poor soil or a dry year are just some of the risks involved in a soil conservation program. However, use of good management, proper equipment and farming methods, good seed, and commercial fertilizer applications all help to lower the risk to a minimum in such a program. The quality of management as well as landlord and tenant relationships must be good.

The importance of these factors can be best illustrated by an example of a farm acquired by the Iowa State College Agricultural Foundation in 1938. The farm consisted of 160 acres of rolling (one to twenty per cent slopes), thin, badly eroded Lindley, Weller, and Clinton Silt Loams. In 1929 a mortgage of $62.00 per acre was put on the farm and in 1938 the farm was appraised for 25 dollars per acre. In 1940 the value of the farm land and buildings was 33 dollars per acre, which will give some idea that the farm was one of very low quality. As far as yields are concerned, the 26 acres of corn in 1938 yielded 31 bushels per acre or a value of 322 dollars and the value of all crops was 551 dollars.

During the next five years, 1939 to 1943, a soil and water conservation program of contour strip cropping,
plowing under legumes as green manure, the application of commercial fertilizer were practiced. The average corn yield during these five years was only 29 bushels per acre and the farm was reappraised in 1943 at 33 dollars per acre, the same value as in 1938. The average net income for the landlord was only 70 dollars per year for the five year period with a top net income in 1943 of 116 dollars. It is clearly seen that the soil and water conservation program was not paying out during these first five years; many tenants and landowners would have been sadly discouraged with such an outlook.

In 1943 a new tenant, who was interested in fully cooperating in a complete soil and water conservation program, was placed on the farm. With the aid of the Soil Conservation Service grassed waterways were started, gullies were filled, and terraces were built. The soil was stabilized on the steeper slopes by use of a four year crop rotation of corn, oats, and two years of legumes. On the more level land a six year crop rotation of corn, oats, corn, oats, and two years of legumes was employed. Records were kept on production during the years 1944 to 1948. The complete story of progress that was made under a program of soil and water conservation plus good landlord and tenant relationships and good management is given in the following table:
### Table 3.

Average Production Records on a 160 Acre Farm Acquired by the Iowa State Agricultural Foundation in 1938.

<table>
<thead>
<tr>
<th></th>
<th>1939-43</th>
<th>1944-48</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation Acres</td>
<td>75</td>
<td>95</td>
</tr>
<tr>
<td>Legume and Rotation Pasture (Acres)</td>
<td>22</td>
<td>36</td>
</tr>
<tr>
<td>Corn Acreage</td>
<td>19</td>
<td>33</td>
</tr>
<tr>
<td>Corn Yield Per Acre</td>
<td>29</td>
<td>49</td>
</tr>
<tr>
<td>Corn Production (Total Bushels)</td>
<td>551</td>
<td>1617</td>
</tr>
<tr>
<td>Hay Yield Per Acre (Tons)</td>
<td>1.2</td>
<td>1.8</td>
</tr>
</tbody>
</table>

*a Table reproduced from (17, p. 19).

It is interesting to note the increase in average corn yields from 29 bushels per acre in 1939-43 to 49 bushels per acre in the 1944-48 period. The 49 bushel per acre average included a low of 8 bushels per acre in 1947 and a high of 70 bushels per acre in 1948. In a move to get more crop acres, the number of acres of permanent pasture was decreased from 72 acres in 1938 to 30 acres in 1948.

Will a program of soil and water conservation pay? It is generally agreed that in this case it certainly has in a financial way. The land has been built up to a higher production level while at the same time saving the soil for future generations. A continuation of such a program is
imperative in order to maintain the production level of the soil and the returns from good crops.

After finding that such a program will increase the production level of the soil one may question what might be the income and investment expectancy for such a program on an average 160 acre farm? Figures based on Project 976 from the Iowa Agricultural Experiment Station on a farm consisting of Marshall Silt Loam and associated soils are shown in the following table:

Table 4.
Income and Investment Expectancy on a 160 Acre Farm in the First Four Years After Adoption of an Erosion Control System.

<table>
<thead>
<tr>
<th></th>
<th>First Year</th>
<th>Second Year</th>
<th>Third Year</th>
<th>Fourth Year</th>
<th>Fifth Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in Income as</td>
<td>-$387</td>
<td>-$242</td>
<td>-$122</td>
<td>+$469</td>
<td>+$804</td>
</tr>
<tr>
<td>Compared to Existing Farming System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Additional Capital Required</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For livestock</td>
<td>-----</td>
<td>$490</td>
<td>-----</td>
<td>$294</td>
<td>$290</td>
</tr>
<tr>
<td>For conservation installations</td>
<td>-----</td>
<td>$206</td>
<td>$294</td>
<td>$119</td>
<td>-----</td>
</tr>
<tr>
<td>For fences, buildings, and miscellaneous</td>
<td>-----</td>
<td>$288</td>
<td>$337</td>
<td>$312</td>
<td>$225</td>
</tr>
</tbody>
</table>

\(^{a}\) Table reproduced from (17, p. 19).
It is shown in Table 4 that the net income will drop during the first three years following the adoption of a soil and water conservation program. Even though gross income will probably be larger, the net income will be lower due to the expense of the conservation program and of buying more livestock to consume the increased amount of roughage. These figures are not at all stable and will vary greatly from farm to farm. The results of a conservation program show very favorably during the fourth and the fifth years after the program is put into effect.

Experimental work set up in 1936-37 and carried on for a period of ten years by the University of Illinois Agricultural Experiment Station in cooperation with the Agricultural Economics Department, the research section of the Soil Conservation Service, and the United States Department of Agriculture offers some interesting facts and figures concerning the effectiveness of a program of soil and water conservation. The experiment covered 270 farms located in different sections of Illinois. Of these farms 135 farms were rated with a low conservation score (little or no conservation was practiced) while the other 135 farms were given a high conservation score (conservation was being practiced). The farms with high conservation scores were matched as nearly as possible with like farms (as to topography, soil type, and size) of low conservation scores. Farms with low conservation scores continued farming
operations as they had in the past while the farms with high conservation scores employed more conservation practices including contouring, strip cropping, grassed waterways, and terraces along with commercial fertilizers, legumes, and crop rotations.

Of the many types of information gathered during the test, yield increases from crops grown on the contour as compared to farming up and down the slope were found to be considerable. Table 5 gives these yield increases and the

Table 5.

Yield Increases for Crops Grown on the Contour Compared with Farming Up and Down the Slope on the Same Illinois Farms.
Seven Year Average 1939-45.a

<table>
<thead>
<tr>
<th>Crop</th>
<th>No. of Farms</th>
<th>Increase from Contouring Bushels per Acre</th>
<th>Per Cent Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>124</td>
<td>6.9</td>
<td>12</td>
</tr>
<tr>
<td>Soybeans</td>
<td>48</td>
<td>2.7</td>
<td>13</td>
</tr>
<tr>
<td>Oats</td>
<td>46</td>
<td>6.9</td>
<td>16</td>
</tr>
<tr>
<td>Wheat</td>
<td>40</td>
<td>3.4</td>
<td>17</td>
</tr>
</tbody>
</table>

a Table reproduced from (21, p. 226).

per cent of increase for the different crops grown.

Figure 2 gives the net income per acre of the 20 low conservation farms as compared with the 20 high conservation farms during the years of the test, 1936-45. The net income
Figure 2. Net income per acre on nearly identical farms with high and low conservation scores - McLean County, Illinois during the test years 1936-45.¹

Figure 3. Crop yield index for the same group of farms as in Table 2.¹

¹ Figure reproduced from (21, p. 226).
per acre was actually lower on the high conservation rated farms than on the low conservation farms for the first year. This was due to increased costs as a result of setting up the conservation program. The five year average 1936-40 shows the high conservation farms going ahead of the low conservation farms in net income per acre even though their expenses were higher. The soil and water conservation program really showed its effects during the second five year period when the difference in the net income averaged 4 dollars and 17 cents per acre more than for the farms not practicing methods of soil conservation. The figures show that by employing conservation methods the costs are returned to the farmer plus a profit and the saving of soil for present and future generations.

Figure 3 shows the same story from a little different angle. The Crop Yield Index was taken as the average of the crop yields during the five years previous to the test years.

Thus far we have been discussing the point of profits to the farmer who employs the methods of soil conservation to his farm. The question of where public responsibility should begin and end is of great importance. If a program of soil and water conservation pays a profit to the farmer, public responsibility should be limited to education and research. On the other hand there are certain instances where construction costs of certain important water control
structures will be so great that a land owner cannot pay for them in his life time. It is in these instances where public responsibility enters in and the costs of such structures should be assumed as a public expense.

One might ask questions as to why and how the public should be interested in problems which appear to be problems of the land owner and tenant. This can best be answered by people living in cities who have disastrous floods which have caused untold damage to their homes and possessions. The floods in Kansas and Missouri during the summer of 1951 have provided the public with a fine example of the need for flood control as practiced by the soil and water conservation program. The people of Kansas City, Topeka, and the many other cities and towns ravaged by the flood waters out of control are vitally interested in such a program of soil and water conservation.

The Little Sioux Watershed Program in northwestern Iowa is now in its early stages and

has a twofold objective: (1) to hold the soil and water in place, thus benefitting the land on which conservation improvements are made, but more important to hold soil and water from damaging all downstream areas with floods and silt (the goal is to reduce maximum waterflow by 20 per cent), and (2) to help maintain the productivity of the land for the benefit of future as well as this generation of citizens. (14, p. 5)

The Little Sioux Watershed Program and similar programs will eventually mean the complete control of soil and water
movement. These programs are important to the farmers living in the area and to the general public.

Some Engineering Aspects of a Soil and Water Conservation Program

In the United States, as in any country, the great basic resources of that country are its soil and water. If these resources are not conserved or put to their greatest use the country will soon begin to deteriorate. In humid areas the problem of conservation is one of safe water removal, while the problem in arid areas is one of conserving the water by storage in dams. In either case, vegetal cover and land use are important, but physical structures built by man are necessary for maximum control and use of the soil and water.

In humid areas before these physical structures can be built, reliable information about the precipitation and the hydrologic data relative to runoff characteristics must be obtained for each watershed. Control of the excess water, or runoff, by physical structures is begun on the high watersheds where streams converge to concentrate the flow of water toward the lower watersheds. Water control structures are also necessary on the lower water sheds where large quantities of water must be safely handled.

Some of these physical structures, more commonly called
water control structures, include terraces, gully heads, plugs, checks, debris basins, contour furrows, ditches, spreading structures, brush wattles, spillways, drop inlets, grass channels, stilling ponds, and revetments. All of these engineering structures must be designed and constructed for adequate capacity, proper provision for maintenance, and a durable long life.

In the arid regions of the West, water control structures and engineering applications must be directed for maximum utilization of water rather than for its safe disposal. Under normal conditions the maximum stream flow does not occur at the same time that plant growth requires the most water. This condition calls for water storage structures. When these storage structures are not available, attempts are made to predict the annual flow and the seasonal distribution for such crops as can be matured with the supplies of water available.

In order to apply water to the soil at the time when needed such physical structures and devices as these are used: checks, drops, headgates, sand traps, measuring devices, pumping plants, sprinkler equipment, spiles, and syphon tubing. Before these units may be used to increase the farm profits the land must be prepared in such a way as to reduce soil erosion and conserve the water supply.
Factors to be Considered in Approaching a Problem
in Soil and Water Conservation Research

Nearly all of the arts and sciences in the field of agriculture will have to be considered when doing research in the conservation of soil and water. Furthermore, this general field consists of a complex of physical, biological, and economic sciences so interwoven that a change in one produces changes in the other two. For this reason before making any changes in one the possible changes in the other two must be carefully studied.

Soil and water conservation has one primary consideration: the soil itself and its reaction to climatic, biological, and hydraulic forces at work under different uses and conditions of the land. Soil is also dynamic in nature and the researcher must understand the effects of expansion and contraction of the soil due to wetting and drying, heating and cooling, freezing and thawing, action of earthworms, and packing soil under various moisture conditions by animals and implements. All of these actions affect the permeability, soil structure, and many other conditions in which we in soil and water conservation are interested. The person doing research must, therefore, recognize the dynamic nature of the soil which determines not only the qualitative, but also the quantitative results that one might expect from any operation or treatment.
It seems logical that the problem may be approached by developing information concerning the natural forces and resistances of nature which are present. These forces of nature include precipitation, solar radiation, gravitational force, molecular forces, and wind forces. On the other hand the resistances of nature include the soil, vegetal cover, watershed characteristics, and channel characteristics. After we recognize the forces and resistances of nature we must compile data concerning the characteristics of each. These data should include such information as the forms of manifestation, the natural distribution, the intensity, the frequency of occurrence, and the range of variation of all of these factors.

An outline of fundamental factors in soil and water conservation and the phases of these factors to be considered in problems of research is as follows:

I. Forces involved in soil erosion, sedimentation, runoff, and water use and management.

A. Precipitation
   1. Form
   2. Distribution (seasonal, annual, cyclical)
   3. Intensities
   4. Amount
   5. Impact characteristics (drop size, velocity)

B. Solar radiation as affecting
   1. Temperature
      a. Air
      b. Soil
      c. Water
      d. Plant (governing evapotranspiration)
   2. Photosynthesis (rate of cover development)
C. Gravity affecting
   1. Water movement
      a. Surface
         (1). Sheet
         (2). Channel
      b. Subsurface movement
      c. Fluid properties
   2. Ice movement
      a. In streams
      b. Mass
   3. Soil movement
      a. In mass
      b. In flowing water
      c. Deposition

D. Molecular forces affecting
   1. Soil
      a. Swelling
      b. Shrinking
      c. Slaking
      d. Dispersion
      e. Drying
      f. Cementation
   2. Water
      a. Evaporation
      b. Capillary (pF)
   3. Soil solution
      a. Base exchange
      b. Leaching and flushing

E. Wind
   1. Velocity and turbulence
   2. Direction
   3. Distribution and duration

II. Resistance to forces involved in soil erosion, sedimentation, runoff, and water use and management

A. Soil
   1. Size of particles
      a. Dispersed (texture)
      b. Aggregated
   2. Structural stability
      a. Cohesion
   3. Permeability
      a. Surface
      b. Subsurface
   4. Moisture
      a. Form
      b. Content
      c. Temperature
B. Cover
1. Snow
   a. Insulation
   b. Moisture absorption
   c. Flow retardation
2. Vegetal
   a. Growth characteristics
   b. Density
   c. Seasonal protection
      (1). Time
      (2). Season
      (3). Residue
   d. Evapotranspiration

C. Watershed characteristics
1. Size
2. Shape
3. Slope—concave or convex, steep or flat, long or short
4. Aspect
5. Drainage pattern and density
6. Geology

D. Channel characteristics
1. Shape and area of cross section
2. Slope
3. Roughness
4. Erodibility of bed and bank
5. Alignment (18, pp. 123-4)
DEVELOPMENT OF THE WHIRLWIND TERRACER

Origin of Terrace Construction in Iowa

Terraces of one form or another have been used as long as history itself has existed. Mention of terraces and their use is made several times in the Bible. Many times in the early history of China, India, Japan, and other Oriental countries have terraces played an important role in agriculture.

The first terraces in the United States were the result of development of the broad base terrace in 1885 by Priestly H. Mangum, a farmer living near Wake Forest, North Carolina. Mangum introduced the broad base terrace by widening the narrow ridges which were previously used in order to allow tillage operations to be carried on over the entire terrace. This is the basic design of the terrace used today throughout America.

Terraces in Iowa are of rather recent origin, the first dating back to 1926. The first terraces were built on a farm about 10 miles south of Atlantic on United States Highway Number 71.

By 1931, farmers in six southwestern counties built some terraces by use of the plow and Vee-type drag. They had no source of technical or hydrologic information for
terrace design. As a consequence, the terraces lacked channel capacity so that tillage operations could not be carried on over the terrace strip.

In 1931 a soil conservation experimental farm was established at Clarinda, Iowa. During that year about 10 miles of terraces were built for water runoff studies. This started widespread interest in the design of terraces and terracing machinery.

History of Whirlwind Terracer Design

The first machine actually designed for building terraces was designed and built in 1934-35 by Leslie W. Johnson as part of the requirement for a Master of Science degree. The work was under the direction of E. V. Collins, Professor of Agricultural Engineering, Iowa State College. The rotary terracer, as it was called, was built from a single 18 inch bottom Oliver plow frame with part of the moldboard cut away to allow space for the vertical spiral rotor. The rotor was driven by the tractor power take off, through a Model A Ford transmission and thence through a set of bevel miter gears in a cast iron housing.

The rotary terracer proved to be very effective as a soil throwing device. Tests proved that soil "batting" was very much less effective than soil throwing by use of a helicoid rotor. Certain information and specifications
concerning rotor peripheral speeds and general rotor design were found to be necessary to build a terrace to the required height.

In 1935 the Soil Conservation Service Law was formed by the United States Congress. Each state in turn designed and passed their laws of soil conservation patterned after the one set up by the United States Congress. Iowa passed its soil conservation law, the Iowa Soil District Law of 1939, in 1939, and since that time interest and activity has been very high in the conservation of the Iowa soil. Today Iowa has 100 soil conservation districts in 98 of its 99 counties.

The next development of the rotary terracer came in 1937 when Paul A. Whistler, as part of his requirement for a Master of Science Degree at Iowa State College, developed the reversible terracer. Whistler was also working under the direction of Professor Collins.

The reversible terracer employed the basic design of the rotary terracer. The reversibility of the machine was attained by use of a right hand spiral rotor and a left hand spiral rotor set 180 degrees apart on a rotating head. The bottom was specially constructed so that by rotating 90 degrees the opposite hand bottom was in plowing position. Energy for reversing the rotor and bottom was stored in a torsion spring by a hydraulic pump. (See Figures 6 and 7.)

The main advantage of the reversible terracer was the
Figure 4. Original Terracer, 1934.

Figure 5. First Mounted Terracer, 1934.
Figure 6. Pull Type Reversible Rotary Terracer, 1938.

Figure 7. Pull Type Reversible Rotary Terracer, 1938.
fact that a terrace could be built entirely from the upper side of the slope allowing it to work particularly well on the steeper slopes. On slopes above 10 per cent the rotary terracer had difficulty in throwing the soil up the slope onto the terrace. Another point in favor of the reversible terracer is that the amount of work required to construct the terracer is considerably less, because the soil is all being thrown down the slope.

The machine, with slight modifications, could be made to do its basic function very well and be easy to operate. However, due to the many parts, difficult and intricate action, and high initial cost as well as expensive repair bills, the machine was not too successful from the overall viewpoint.

During the year 1938, Richard A. Duncan, as a partial requirement for a Master of Science Degree at Iowa State College, made changes in the design of the reversible terracer designed and constructed a year earlier by Whistler. The project was to redesign the functional parts of the reversible terracer to eliminate some of the weaknesses of the earlier model. Duncan, also under the direction of Professor Collins, redesigned and built a new hydraulic pump and a new plow bottom. The changes proved to be effective and quite an improvement toward getting a more positive reversing action of the rotor and plow bottom. The machine
was still complicated and bulky with too many intricate parts.

Review of Problem in 1950

In 1950, research was started to increase the efficiency of the Whirlwind Terracer. Ray E. Armstrong, as part of the requirement for a Master of Science Degree from Iowa State College, was working under the direction of Professor Collins. A full statement of the problem may be had by consulting Armstrong's thesis, "Test of Modification of Parts of Whirlwind Terracer". In general, his problem was concerned with a description of the "ideal terracing machine" as to basic design and operation, power requirement, and cost. Armstrong then developed a complete procedure for computing "Annual Cost of Construction of Terraces".

Along with the problem of basic design of the terracer, Armstrong considered the plow bottom design and the rotor design. Four different types of plow bottoms were designed and built. Tests were run on each bottom. Variation in forward speed (3-3/4 and 5 miles per hour), plow depths (5 and 7 inches), and rotor level and running tilted at 11 degrees were run and all combinations of the variables were checked. These tests were all run using the 14 inch pitch, 14 inch diameter, helical, double flight rotor. One test was run using a ditching rotor of special design.
Soil samples were caught in pans, the centers of which were placed at each 1 foot distance from the right edge of the rotor. The soil samples were weighed on a scale and by a simple calculation the work done on the soil in each pan was figured. These figures, the work done and the soil weight were placed in tables and plotted on graphs.
PROBLEM AND RESULTS IN 1951

Problem

Armstrong pointed out that future studies should be made on the problem of rotor design and terrace construction technique. The reason for this study will be to improve the rotor design. The rotor to be used in this study has 18 inch diameter, 1¼ inch pitch, double flight, and is 18 inches tall. This rotor is 4 inches greater in diameter than the one used in 1950. (See Figures 8 and 9).

From the studies in 1950 it was evident that by using a rotor of larger diameter and by moving the centerline rotor back and a little to the right greater efficiency would be obtained. Moving the rotor back and a little to the right would cause more of the furrow slice to enter the left side of the rotor's vertical centerline. This placement of the furrow slice on the rotor would allow more of the soil to enter onto the rotor flights, causing more of the soil to be pitched into the air and causing it to be thrown farther.

For comparative test purposes, the peripheral speed of the rotor was held as near the same as the 1950 tests as possible. Using a 1¼ inch diameter rotor and the high gear ratio of 2:1 on the terracer transmission we find:
Figure 8. Whirlwind Terracer With 18 Inch Wide Bottom and 18 Inch Diameter Helical Rotor.

Figure 9. Close up View of 18 Inch Diameter Helical Rotor and 18 Inch Wide Bottom.
2:1 Gear Ratio on Terracer Transmission,  
536 Revolutions Per Minute--Power Takeoff Speed,  
\[(2)(536)(\pi)(\frac{14}{12}) = 3930 \text{ feet per minute.}\]

As a comparison with the new 18 inch diameter rotor we find:

1.75 Gear Ratio on Terracer Transmission,  
536 Revolutions Per Minute--Power Takeoff Speed,  
\[(1.75)(536)(\pi)(\frac{18}{12}) = 4420 \text{ feet per minute.}\]

Using the gear ratios which were on the terracer transmission it will be noted that an increase of 4420 - 3930 = 490 feet per minute peripheral speed of the new 18 inch diameter rotor and 1.75 to 1 gear ratio is obtained over the peripheral speed of the old 14 inch diameter rotor and the 2:1 gear ratio.

The Agricultural Engineering Department had two of the old Parson Terracers which were badly in need of complete overhaul. The transmission was taken completely apart and each piece was cleaned and carefully inspected before putting it back into the transmission case. Replacement parts included the front bearing on the power takeoff shaft and the front bearing case cover on the terracer transmission case. These parts were taken from the transmission of the second Parson Terracer.

The next problem was building onto the back end of the terracer plow a frame so that the larger diameter rotor could be moved back and slightly to the right. Stock
material for making the frame was cut from the frame of the second terracer plow. A frame extension, as shown in Figures 10 and 11, was built onto the old plow frame. This would allow us to use interchangeably the old 14 inch diameter rotor and the old plow bottom as well as the new 18 inch diameter rotor and the new plow bottom. The power drive shaft extending from the rear of the terracer transmission to the rotor gear housing was replaced with a longer shaft to accommodate moving the new larger rotor rearward.

A special bottom was made, similar to "Bottom No. 3" used in 1950 by Armstrong. The bottom was built to plow a 24 inch furrow and was made up as shown in Figure 13. The moldboard was cut from a regular Oliver plow moldboard, heated in a forge, and shaped. During the shaping, numerous cracks appeared in the moldboard. It was decided that the moldboard should be cut to eliminate serious cracks.

Three short Oliver Raydex plow shares were electrically welded together to form a 24 inch share. This special share was made with increased suction in the plow point to keep the plow at an even shallow depth. In order to allow the plow to take a 24 inch cut an extension hub was used.

An extra pan holder rack and eleven new pans were made to allow coverage of the complete distance which the terracer would throw the soil. The new pans were made from lighter gauge aluminum sheet and were brought up to the same
Figure 10. Close up Showing 18 Inch Diameter Rotor and 18 Inch Wide Bottom.

Figure 11. Frame Addition for Changes Using the 24-Inch Wide Bottom.
Figure 12. Pan Holder and Pan.

Figure 13. Flow Bottom 24 Inches Wide.
weight as the old pans by bolting weight strips to the bottom of the pan. The pan holder was made from 1/4 inch diameter mild steel rod electrically welded.

Field Test Procedure

Previous to running field tests in 1951 the terracer was run about seven and one-half hours to scour off the moldboard and share. The flights on the rotor were scouring on the outer three inches. During the preliminary plowing, soil of various moisture contents was plowed. It was found that soil whose condition was ideal for plowing, or slightly dryer, would throw the greatest amount of soil the greatest distance. No data were taken on this phase of the work.

A four and one-half acre field of barley stubble was selected for testing. The field was located straight west from the buildings on the agricultural engineering farm, and next to the Fort Dodge, Des Moines, and Southern Railroad tracks.

Two weeks earlier the barley was windrowed and combined; the stubble was clipped with a power mower, raked together and baled. After the grain was harvested, two and one-half inches of rain fell, mellowing the soil, and making it in ideal condition for terracer operation. The area chosen for running the tests was a level spot toward the north end of the field.
The field procedure for the terracer tests included plowing a strip of land about 30 feet wide and 300 feet long. This allowed the soil pans to be set on top of the plowed ground and made sure everything was ready for the test runs. One round was plowed after the plow had been set at the correct depth for each test run.

Pans for catching the thrown soil were placed in wooden racks just before each test run. (See Figures 14 and 15.) Placement of pans started at the right edge of the rotor. The first two pans, one 6 inch and one 12 inch, had removable sides to allow the tractor tire to roll in the furrow without damage. (See Figure 16.) Each successive 12 inch pan was placed end to end for a distance of about 30 feet. After the terracer had passed, the removable sides were then placed down on the flat sheets to confine the sample of soil thrown. Each pan was then weighed and the weight of the soil in each was recorded. (See Figure 17.)

Each empty pan had been carefully weighed on a sensitive beam balance scale, showing a weight of 1.32 pounds. The cradle for the weighing pans weighed 1.68 pounds, making a total tare weight of three pounds for the pan and cradle.

Information at time of tests included:

2. Temperature: 65° to 70° F.
3. Wind velocity and direction: southwest, 5 to 6 miles per hour.
4. Soil condition: very good on high ground, but wet and sticky on low ground.
Figure 14. Pan and Rack Placement for Tests.

Figure 15. Pan and Rack Placement for Tests.
Figure 16. False Bottom Bottom Box Frame.

Figure 17. Soil Weighing Equipment.
Vegetal cover: barley stubble with new seeding of hubam sweet clover and volunteer soy beans cut back with a mower and baled.

Tractor data included:

1. Model: Oliver Row Crop with wide adjustable front axle.
3. Engine serial number:
4. Wheeltype:
   a. rear wheels: cast, steel disk
   b. front wheels: cast with wheel weights.
5. Speeds:
   a. first gear: 2.29 M.P.H.
   b. second gear: 3.16 M.P.H.
   c. third gear: 4.27 M.P.H.
   d. fourth gear: 5.67 M.P.H.

This procedure of catching and weighing soil in pans was used in a series of tests outlined below.

I. Using the 24 inch bottom, 18 inch diameter rotor and the terracer transmission gear ratio of 1.75 to 1:
   A. Plow depth of 3 inches and a forward tractor speed of second gear.
   B. Plow depth of 3 inches and a forward tractor speed of third gear.
   C. Plow depth of 3 inches and a forward tractor speed of fourth gear.
   D. Plow depth of 5 inches and a forward tractor speed of second gear.
   E. Plow depth of 5 inches and a forward tractor speed of third gear.
   F. Plow depth of 5 inches and a forward tractor speed of second gear, terracer transmission gear ratio 2:1.
II. Using the 18 inch bottom, 18 inch diameter rotor and the terracer transmission gear ratio of 1.75 to 1:

Repeat of the above tests A through F.

Discussion of Field Test Results

The weights of soil in each pan as caught by one passing of the terracer unit were recorded in the field. The weight of soil in each pan was plotted on the graphs to make up data for the "Soil Placement Curve" for each field test.

The amount of work as shown by the Cumulative Work Curves, or the amount of soil and the distance of displacement as measured by the weight and displacement, includes an energy factor which is proportional to the weight distance calculations from which the Cumulative Work Curves were obtained.

The kinetic energy of a particle is defined as the capacity of the particle for doing work as a result of its velocity. The kinetic energy of a particle can be determined by computing the work which must be done on a particle to reduce its velocity to zero. Kinetic energy has the same units as work; that is, the dimensions FL and the common units of foot pound, inch pound, dyne centimeters, and so on. The dimensions of mass are \( \frac{FL}{T} \) and the dimensions of velocity are \( \frac{L}{T} \). The formula for kinetic energy is:
Kinetic energy is a scalar quantity since the work which can be done depends only upon the mass of the particle and the magnitude of its velocity and not on the direction of the velocity. The mass is always a positive quantity and the velocity squared; therefore the kinetic energy is always positive.

Applying the above information to the case of the whirlwind terracer, a helical-rotor imparts a velocity to a particle of soil. As the soil particle strikes the terrace ridge or soil pan its velocity drops to zero. The kinetic energy the particle had just before its velocity became zero is transformed into heat and is used to deform the arrangement of soil particles on the terrace ridge or in the soil pan.

The values of work in the Cumulative Work Curves are weight-distance relationships and do not take into account the values of kinetic energy of the particle just before it strikes the soil in the pan. The values of work from the Cumulative Work Curves show only the useful work done by the mass of the particles of soil and the velocities imparted to them by the helical rotor.

Test results shown on Figures 18, 19 and 20 were taken
Work and Soil Placement Curves as Thrown by Whirlwind Terracer.

18" and 24" Width Plow Bottoms
18" Dia. Rotor
2nd Gear 3" Deep

Figure 18. Work and Soil Placement Curves as Thrown by Whirlwind Terracer. 18 Inch and 24 Inch Wide Plow Bottoms, 2nd Gear, 3 Inches Deep, Rotor to Power Takeoff Speed 1.75:1.
Figure 19. Work and Soil Placement Curves. 3rd Gear, 3 Inches Deep, Rotor to Power Takeoff Speed 1.75:1.
Figure 20. Work and Soil Placement Curves. 4th Gear, 3 Inches Deep, Rotor to Power Takeoff Speed 1.75:1.
Figure 21. Work and Soil Placement Curves. 2nd Gear, 5 Inches Deep, Rotor to Power Takeoff Speed 1.75:1.
Figure 22. Work and Soil Placement Curves. 3rd Gear, 5 Inches Deep, Rotor to Power Takeoff Speed 1.75:1.
Figure 23. Work and Soil Placement Curves, 2nd Gear 5" Deep, Rotor to Power Takeoff Speed 2:1.

Note: Rotor Transmission Ratio 2:1, 1951

- Cumulative Work Curves
- Soil Placement Curves

Tare soil weight 3 pounds

DISTANCE IN FEET FROM ROTOR

- 18" Bottom
- 24" Bottom

WORK CURVES

CUMULATIVE SOIL WEIGHT

FOOT POUNDS OF WORK (CUMULATIVE)
Figure 24. Effect of Ground Speed on Soil Distribution and Work Curves. 18 Inch Wide Plow Bottom. Rotor to Power Takeoff Speed 1.75:1. Plowing 3 Inches Deep.
Figure 25. Effect of Ground Speed on Soil Distribution and Work Curves. 
24 Inch Wide Plow Bottom. Rotor to Power Takeoff Speed 1.75:1. 
Plowing 3 Inches Deep.
Figure 26. Effect of Ground Speed on Soil Distribution and Work Curves:
18 Inch Wide Plow Bottom, Rotor to Power Takeoff Speed 1:25.1.
EFFECT OF GROUND SPEED ON SOIL DISTRIBUTION AND WORK CURVES
PLOWING 5" DEEP

2nd GEAR
3rd GEAR
18" DIA. ROTOR
18" WIDTH OF PLOW BOTTOM
ROTOR GEAR RATIO 1:25.1, ELECTRIC
POWER-OFF, OLIVER "77" GASOLINE
YEAR-SUMMER 1951

CUMULATIVE SOIL DISTRIBUTION CURVES
CUMULATIVE WORK CURVES

POUNDS OF SOIL
DISTANCE IN FEET FROM ROTOR

FOOT POUNDS OF WORK (CUMULATIVE)
Figure 27. Effect of Ground Speed on Soil Distribution and Work Curves.
with the plow running 3 inches deep, the rotor running 1.75 times faster than power takeoff R.P.M. and in the respective tractor gears of second, third, and fourth. Figure 24 shows a comparison of the test results given in Figures 18, 19 and 20. Note the position of the cumulative soil distribution curves which show the greater forward speed, fourth gear, deposits a greater amount of soil between the distance of 12 and 20 feet from the rotor than the two lower speeds. This indicates that as the forward speed increased, more soil moved toward the rotor center line in the time which the flight passed vertically through the furrow slice. Throwing more of the soil nearer the rotor centerline, allowed the rotor to get a better hold on the soil and thus throw it farther.

The "Cumulative Work Curves" follow a pattern similar to the "Cumulative Soil Distribution Curves". This was to be expected for the work curves originate from the soil distribution curves. The weight of soil thrown for each foot distance from the rotor was multiplied by the number of feet from the rotor to give the work done on the soil at that respective point.

The levelling off of the work curve after the 14 foot position (Figure 20) may best be explained by the decrease in the tractor R.P.M. due to the shortage of tractor power in fourth gear. At this point the tractor R.P.M. was probably less than 70 per cent of the rated tractor R.P.M.
The amount of soil left near the rotor was actually less when traveling in fourth gear than when traveling in second gear. Note also that the greatest amount of soil was deposited between 10 and 15 feet from the rotor when traveling in fourth gear. The other amounts of soil deposited were fairly uniform out to about 18 feet from the rotor. The rotor handled the complete furrow slice throwing amounts of soil as far as 29 feet in second gear, 28 feet in third gear, and 21 feet in fourth gear.

It might be concluded from these data that the higher the forward speed the greater the throwing action of the rotor on the soil.

Similar conclusions may be obtained by examining Figure 25 which shows similar results for the 2 1/4 inch bottom as Figure 24 showed for the 18 inch bottom. More soil was left near the rotor when running in second and third gear than when running in fourth gear. This may be explained by the fact that a combination of slower forward speed and greater rotor speed will leave more soil near the rotor. By having a slow forward speed the soil will not get into the rotor as well because of the soil's own inertia to throw itself into the rotor. Also with a greater rotor speed the vertical travel of the rotor flights is so fast that insufficient time is allowed for the soil to get into the rotor. The greater amount of soil left by the side of the rotor is due to the fact that the rotor cannot handle
handle the larger amount of soil in a 24 inch slice as well as that in an 18 inch slice. Note also the characteristic slump in the fourth gear test similar to one in Figure 24. It is again due to the slow up in the tractor R.P.M. due to the lack in tractor horsepower.

In some instances the work curve is built up to its highest level 3-1/2 feet nearer the rotor when running in fourth gear as compared to running in second gear. This is shown clearly in Figure 25 using the second and fourth gear work curves. The second gear builds up to the 170 foot pound level of work at about 13.5 feet from the rotor while the fourth gear does this as near the rotor as 10.5 feet. This is an indication that less rotor speed, due to a shortage of tractor power while traveling in fourth gear, deposits the soil nearer the rotor. In the case of the second gear operation the soil is generally deposited farther from the rotor due to the fact that higher rotor speed achieves better throwing action. Figures 26 and 27 represent the data from Figures 21 and 22 with the effects of ground speed on the throwing of soil while plowing 5 inches deep using 18 inch and 24 inch bottoms respectively. Two speeds, second and third gears, were used in the testing. The soil distribution curves of Figure 26 show very clearly that less soil was left near the rotor when traveling in third gear as compared to traveling in second gear. This condition again confirms the idea that higher forward speed gives
greater inertia to the soil particles. This throws them nearer the rotor centerline where the rotor in turn can get a better hold on the soil particles and thus throw them more effectively. Tests on Figure 26 show the soil not thrown as far because of the limiting tractor horsepower.

It is interesting to note on Figure 26 that more soil was left near the rotor while traveling in second gear than in third gear. These conditions are the same as was the case with slower forward travel and faster vertical movement of the rotor flights.
PROBLEM AND RESULTS IN 1952

Problem

Today the general trend in farm implements is toward a mounted unit on a tractor or on some other source of power. In this way it becomes a self-propelled unit. Self propulsion of farm implements has opened much new thinking in the engineering design of farm implements and has given the farmer a unit which is easier to operate, with decreased weight and increased operating efficiency.

Under the direction of Professor Collins, a previously built reversible rotary terracer was mounted on a Ford tractor. The terracer was originally designed and built by Whistler in 1937. It was redesigned by Duncan in 1938 to eliminate some of the weaknesses which appeared during Whistler's testing.

In the spring of 1952 the old reversible rotary terracer was stripped of the parts that it did not need as a mounted unit on a tractor. The continuous running hydraulic pump, the undercarriage, the reversing controls, and other miscellaneous equipment were removed in order to plan the method of mounting the terracer on the Ford tractor. Starting from the main support frame a new machine was planned.
The first job was that of bending the strap irons (3/4 inch by 3 inches) of the main support frame to form a bail which had been planned for attaching the two lower lifting links of the tractor. Using some steel plate (10 inches by 3/8 inch) a housing was built to carry the tractor top link as shown in Figures 28 through 31. Four new springs were purchased to force the oil out of the cylinder after the machine had been rotated. To operate the reversing cylinder a hydraulic line was built to the tractor hydraulic pump.

In order to have the power take-off drive shaft running with as little angularity as possible the drive shaft was raised 11 inches above the center line of the tractor power takeoff shaft. (See Figure 34). The drive was a 5/8 inch pitch, high speed, double roller chain. The top-driven sprocket was mounted on a welded shaft and plate assembly bracket which in turn was bolted directly onto the tractor frame.

The first public showing of the machine was during the Agricultural Engineering Field Day, June 27, 1952. It was a fine day but an all night rain the night before made the soil slippery on top. Several rounds were run to make last minute checks before showing the machine. On the last round the plow share struck a rock which nearly folded the main frame of the terracer. The results of this accident are shown in Figures 30 and 31. Note particularly Figure 30.
Figure 28. Original Lift Frame for Tractor Mounted Reversible Rotary Terracer.

Figure 29. Original Lift Frame for Tractor Mounted Reversible Rotary Terracer.
Figure 30. Original Lift Frame for Tractor Mounted Reversible Rotary Terracer.

Figure 31. Closeup of Bent Main Frame of Original Lift Frame on the Tractor Mounted Reversible Rotary Terracer.
Figure 32. Mounting Bracket for Power Drive of Tractor Mounted Reversible Rotary Terracer.

Figure 33. Mounting Bracket for Power Drive of Tractor Mounted Reversible Rotary Terracer.
Figure 34. Power Drive of Tractor Mounted Reversible Rotary Terracer.

Figure 35. Yoke and Shortened Top Link Assembly.
with the meter stick clamped to the housing and Figure 31 showing a closeup of the main support frame irons. Earlier work with the unit which failed indicated that if bending occurred it would occur in the main support frame irons.

After the field day the machine was brought back to the Agricultural Engineering Machinery Laboratory and immediately plans were made for rebuilding the main support frame. The new plans called for cutting the main support frame irons just ahead of the mounting for the rotor housing. The ends of the irons were cut in an arc to fit a tube (3-1/2 inch outside diameter) used to support the machine. Basic engineering principles were satisfied when the large torque loading at this point was supported with a torque tube. The torque tube was welded in place and clamp irons were welded over it to give added strength against twisting. On the ends of the torque tube the standards for lifting and controlling the machine were welded in place. A yoke was built to fit between the standards and take the top hitch link of the tractor. (See Figure 35.) The top hitch link was a regular Ford tractor link shortened to a length of 25-1/8 inches. A bushing was welded on the end of the link to make a connection with the yoke. This lift frame proved to be very strong and sturdy, handling the weight of the terracer unit well at all times. (See Figures 36 and 37.)
Figure 36. New Lift Frame on Tractor Mounted Reversible Rotary Terracer.

Figure 37. New Lift Frame on Tractor Mounted Reversible Rotary Terracer.
Figure 38. Reversible Rotary Terracer Mounted on a Ford 8N Tractor.

Figure 39. View Showing the Reversing Feature of the Mounted Reversible Rotary Terracer.
Figure 40. Reversible Rotary Terracer Mounted on a Ford 8N Tractor.

Figure 41. Reversible Rotary Terracer Mounted on a Ford 8N Tractor.
Field Test Procedure

Further tests were run during the summer of 1952 on the same terracer on which tests were run in 1951. Tests were run to show the effect of ground speed and rotor gear ratio on the soil distribution curves and the work curves. The 18 inch bottom was used on all tests in 1952 because tests during 1951 showed conclusively that a 24 inch furrow slice was entirely too much for an 18 inch diameter rotor to handle in plow depths greater than 3 inches. A plow depth of 5 inches was chosen because that seems to be an average figure for regular plowing. The power source was a 1951 Massey Harris "44" Diesel Row Crop tractor. The tractor engine serial number was 44DR 3150. The rear wheels were of the regular row crop type cast steel disk wheels with air in the tires. Tractor gear speeds, at a nominal engine speed of 1450 R.P.M., included: first gear, 1.92 M.P.H.; second gear, 2.97 M.P.H.; third gear, 4.21 M.P.H.; fourth gear, 5.58 M.P.H.

The site used for testing purposes was just south of the tile spacing experiment on the Agricultural Engineering Farm. The field was in red clover hay for the first year, the stubble had been clipped back with a mower, and the crop residue had been baled.

Plowing was started far enough up on the hillside so that the soil thrown by the rotor would not be thrown into
the existing terrace basin. The plowing was also done parallel to the terrace.

Several rounds were plowed before starting the test work in order to give the operator a chance to get acquainted with the tractor and machine.

The first tests were to be run in first gear of the tractor with the plow running 5 inches deep, and the rotor gear ratio set at 1:1. The racks and pans were placed in a row making a 90 degree angle with the direction of machine travel. A pass was made and the soil in each pan was weighed and recorded. Two runs of each test were made and recorded.

The following tests were run during the summer of 1952:

I. Using the 18 inch bottom and the 18 inch diameter rotor with the terracer transmission ratio set at 1:1:
   A. Plow depth of 5 inches and the tractor in first gear.
   B. Plow depth of 5 inches and the tractor in second gear.
   C. Plow depth of 5 inches and the tractor in third gear.

II. Using the 18 inch bottom and the 18 inch diameter rotor with the terracer transmission ratio set at 1:1.75:
   A. Plow depth of 5 inches and the tractor in first gear.
   B. Plow depth of 5 inches and the tractor in second gear.
III. Using the 18 inch bottom and the 18 inch diameter rotor with the terracer transmission ratio set at 1:2:

A. Flow depth of 5 inches and the tractor in first gear.

Weather information at time of tests:

1. Weather: clear and warm.
2. Temperature: 70°F to 75°F.
3. Wind velocity and direction: southwest 10 to 12 miles per hour.
4. Soil condition: soil moisture near field capacity, soil in excellent condition.
5. Vegetal cover: red clover meadow for three years. The area was clipped back with mower and the residue was baled.

Discussion of Field Test Results

Tests on rebuilt Parson's Whirlwind terracer

The effect of ground speed is very clearly shown in Figure 44, a composite of Figures 42 and 43. The soil distribution curves show much less soil remaining near the rotor when the tractor was traveling in second gear than when traveling in first gear. More soil was deposited between 2 and 13 feet while traveling in second gear but while traveling in first gear more soil was thrown between 13 and 20 feet. The reason for this is that the engine R.P.M. was down to about 80 per cent of normal while running in second gear and could not throw the soil as far. The work curves built up as expected, with the second gear curve
Figure 42. Cumulative Soil Placement and Cumulative Work Curves as Thrown by Whirlwind Terracer. 18" Width Plow Bottom, 18" Dia. Rotor, 1st Gear 5" Deep, Rotor Gear Ratio 1.75:1, Massey Harris "44" Diesel.
Figure 43. Cumulative Soil Placement and Cumulative Work Curves, 18 Inch Wide Plow Bottom, 2nd Gear, 5 Inches Deep, Rotor to Power Takeoff Speed 1.75:1.
Figure 44. Effect of Ground Speed on Soil Distribution and Work Curves. 18 Inch Wide Plow Bottom, Plowing 5 Inches Deep, Rotor to Power Takeoff Speed 1.75:1.
Figure 45. Work and Soil Placement Curves as thrown by Whirlwind Terracer.

18" Width Plow Bottom
18" Dia. Rotor
1st Gear, 5" Deep
Massey Harris "44" Diesel
Note: Rotor Transmission Ratio 2:1

Work and Soil Placement Curves. 18 Inch Wide Plow Bottom, 1st Gear, 5 Inches Deep, Rotor to Power Takeoff Speed 2:1.
Figure 46. Effect of Rotor to Power Takeoff Speed Ratio on Soil Distribution and Work Curves. 18 Inch Wide Plow Bottom, 1st Gear, 5 Inches Deep.
Figure 47. Cumulative Soil Placement and Cumulative Work Curves. 18 Inch Wide Plow Bottom, 1st Gear, 5 Inches Deep, Rotor to Power Takeoff Speed 1:1.
Figure 48. Cumulative Soil Placement and Cumulative Work Curves. 18 Inch Wide Plow Bottom, 2nd Gear, 5 Inches Deep, Rotor to Power Takeoff Speed 1:1.
Figure 49. Cumulative Soil Placement and Cumulative Work Curves, 18 Inch Wide Plow Bottom, 3rd Gear, 5 Inches Deep, Rotor to Power Takeoff Speed 1:1.
Figure 50. Effect of Ground Speed on Soil Distribution Curves. 18 Inch Wide Plow Bottom, Plowing 5 Inches Deep, Rotor to Power Takeoff Speed 1:1.
Width Plow Bottom
14" Dia. Rotor
1st Gear - Soil Loose
Ford Standard 8N Tractor

Figure 51. Cumulative Soil Placement and Cumulative Work Curves, 16 Inch Wide Plow Bottom, 14" Inch Diameter Rotor, 1st Gear in Loose Soil.
Figure 52. Cumulative Soil Placement and Cumulative Work Curves. 16 Inch Wide Plow Bottom, 14 Inch Diameter Rotor, 2nd Gear in Loose Soil.
building up nearer the rotor and the first gear curve building up farther from the rotor.

The effect of the ratio of rotor speed to power takeoff speed was investigated. On the old Parson's Whirlwind Terracer a transmission was mounted to give a variety of speeds to the rotor. The rotor to power takeoff speed ratios included 1:1, 1.75:1, and 2:1.

Figure 46 shows the effect of the various speed ratios on the distribution of thrown soil and on the work done on the soil. With the tractor traveling in first gear and a rotor to power takeoff speed ratio of 1:1, soil was thrown no more than 13 feet. The 1.75:1 ratio deposited soil as far as 25 feet from the rotor, while the 2:1 ratio deposited soil as far as 30 feet from the rotor. These figures were all taken under the same conditions while plowing 5 inches deep and traveling in first gear. The amount of soil that was thrown 25 and 30 feet was actually very small. On the other hand, it is shown in Figures 42 and 45 that considerable amounts were thrown as far as 20 feet in each instance.

Figure 50 shows the effect of forward speed on distance and amount of soil thrown. When traveling in first gear considerable amount of soil is left near the rotor; when traveling in second gear less soil is left near the rotor; and when traveling in third gear very much less soil is left near the rotor. This substantiates the claim that
increasing forward speed gets more of the soil into the rotor and gives the rotor a better chance of throwing the soil.

Note that soil was thrown farther in first gear than in second and third successively. This might be explained by loss in R.P.M. on the part of the tractor in shifting to higher gears.

The 1952 field tests were not without difficulties. The clover meadow was two years old and the root system of the clover had grown quite large and extensive. Due to dull plow shares the clover roots were pulled up and dragged along the face of the plow share instead of being cut. With the clover as well established as it was, it was difficult for the rotor to beat the clover stubble and roots from the soil. Considering all factors, the 1952 field tests were successful and certain conclusions can be made in regard to terracer plow design and rotor design.

Tests on tractor-mounted reversible rotary terracer

Test results shown on Figures 51 and 52 are the results of field trials using the tractor-mounted unit. Because of low tractor engine power the test results indicate very little as far as the possibilities of this type of unit are concerned.

An attempt was made to plow about 3 inches deep in the unplowed red clover meadow, but proved to be beyond the
limit of the tractor engine's capacity. Clover roots were not sheared but were pulled out of the ground. The soil was well knit together by the clover roots and was difficult to beat apart by the terracer rotor.

Because no reasonable test could be given the mounted terracer in the unplowed ground, the next trial run was made in the previously plowed soil. Under those conditions the tractor engine handled the mounted terracer in first and second gear. Figures 51 and 52 indicate that very little soil was thrown any appreciable distance when the tractor travelled in first or second gear. However in the second gear run considerably more soil was deposited between 5 and 11 feet than in the first gear run. The greater deposition is indicated in the work curve shown just below the soil distribution curve.
SUMMARY AND CONCLUSIONS

Tests on the whirlwind terracer, using the 18 inch diameter double flight helical rotor, were quite satisfactory and show definite improvement over the 14 inch diameter rotor. Test results indicated that use of the high rotor gear ratio resulted in throwing small amounts of soil considerable distance, while use of the low gear ratio resulted in throwing larger amounts of soil a relatively short distance. The ideal condition would lie somewhere between these two extremes. A rotor gear ratio of 1.50:1 might improve conditions considerably. This suggestion is based on an assumption that slowing the rotor speed would allow the soil more time to get between flights and more soil would be thrown a greater distance.

To improve the efficiency of the helical rotor type of terracer the plowed soil must be directed into the rotor flights in a more positive fashion. The furrow slice tends to roll, as it does in the ordinary plowing operation, instead of going into the rotor where it can be thrown. Perhaps a shield might be built in such a way that the soil would be forced into the rotor flights.

Basically mounting a terracer on a tractor is sound and a great improvement over the pull type of unit. The machine
is easier to adjust and to operate, and is less weighty when built as a mounted unit.

Field tests indicated that the first improvement should be to increase the engine power. It is important to have a tractor with a continuously running hydraulic pump. The use of a two-way valve would make it possible to reverse the rotors more easily.

The angularity of the power drive shaft in the raised as well as in the operating position is a problem. Operation was improved when the rotor gear housing was relocated in order to get the same angle on the rear universal joint as on the forward universal joint. This made for a smooth running rotor and any changes in angular velocity were then in the intermediate link of the power shaft. A new power shaft designed to operate under extreme angularity should help this condition.

The high speed double roller chain drive seems to be satisfactory, but an enclosed gear unit running in oil would be a fine improvement.

Much work needs to be done to develop procedures for building terraces on various grades with the reversible rotary unit. Time trials need to be run to show some of the advantages of the reversible feature in this terracer. The feature of reversibility in terracers is sound and it is hoped that work has just begun toward building a machine with all these features.
BIBLIOGRAPHY


APPENDICES
Appendix A.

Whirlwind Terracer Test Data,
Using the 18 Inch Diameter Helical Rotor
and the 18 Inch Wide Flow Bottom. 1951.
### Whirlwind Terracer Test

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<th>Ft. from rotor</th>
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**Plow Depth** 3" **Bottom** 18"

**Ground Speed** 2nd Gear 13" Dia. Rotor

**Rotor to Power Takeoff Speed Ratio** 1.75:1
## Whirlwind Terracer Test

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Flow Depth 3"  18" Bottom
Ground Speed 3rd Gear  18" Dia. Rotor

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Plow Depth 3" Bottom 18"

Ground Speed 4th Gear 18" Dia. Rotor

Rotor to Power Takeoff Speed Ratio 1.75:1
### Whirlwind Terracer Test

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- **Flow Depth**: 5" - 18" Bottom
- **Ground Speed**: 2nd Gear - 18" Dia. Rotor
- **Rotor to Power Takeoff Speed Ratio**: 1.75:1
## Whirlwind Terracer Test

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### Notes
- **Plow Depth**: 5"  
- **Ground Speed**: 3rd Gear  
- **Rotor to Power Takeoff Speed Ratio**: 1.75:1

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- **18" Bottom**
- **18" Dia. Rotor**

Rotor to Power Takeoff Speed Ratio 1.75:1
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**Plow Depth** 5"  18" Bottom

**Ground Speed** 2nd Gear  18" Dia. Rotor

**Rotor to Power Takeoff Speed Ratio** 2:1
Appendix B.

Whirlwind Terracer Test Data
Using the 18 Inch Diameter Helical Rotor
and the 24 Inch Wide Flow Bottom. 1951.
### Whirlwind Terracer Test

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**Flow Depth**: 3"  
**24" Bottom**  
**Ground Speed**: 2nd Gear  
**18" Dia. Rotor**  

**Rotor to Power Takeoff Speed Ratio**
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**Flow Depth** 3"  
**Ground Speed** 3rd Gear  
**Rotor to Power Takeoff Speed Ratio** 1.75:1
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Flow Depth: 3\"  2\" Bottom  
Ground Speed: 4th Gear  
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Flow Depth 5" Bottom 24" Ground Speed 2nd Gear 18" Dia. Rotor

Rotor to Power Takeoff Speed Ratio 1.75:1
### Whirlwind Terracer Test

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**Flow Depth** 5"  
**Ground Speed** 3rd Gear  
**24" Bottom**  
**18" Dia. Rotor**  

Rotor to Power Takeoff Speed Ratio 1.75:1
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Flow Depth 5" 24" Bottom
Ground Speed 2nd Gear 18" Dia. Rotor

Rotor to Power Takeoff Speed Ratio 2:1
Appendix A.

Whirlwind Terracer Test Data
Using the 18 Inch Diameter Helical Rotor
and the 18 Inch Wide Plow Bottom. 1952.
### Whirlwind Terracer Test

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- Flow Depth: 5" 18" Bottom
- Ground Speed: 1st Gear 18" Dia. Rotor
- Rotor to Power Takeoff Speed Ratio: 1:1
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Flow Depth 5" Bottom 18" Dia. Rotor

Ground Speed 2nd Gear 18" Dia. Rotor

Rotor to Power Takeoff Speed Ratio 1:1
### Whirlwind Terracer Test

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<td>Test I    Test II Ave.</td>
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- Flow Depth: 5" to 18" Bottom
- Ground Speed: 3rd Gear to 18" Dia. Rotor
- Rotor to Power Takeoff Speed Ratio: 1:1
## Whirlwind Terracer Test

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- **Plow Depth**: 5" 18" Bottom
- **Ground Speed**: 1st Gear 18" Dia. Rotor
- **Rotor to Power Takeoff Speed Ratio**: 1.75:1
### Whirlwind Terracer Test

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- **Flow Depth:** 5" and 18" Bottom
- **Ground Speed:** 2nd Gear
- **Rotor to Power Takeoff Speed Ratio:** 1.75:1

**Dia. Rotor**
### Whirlwind Terracer Test

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<th>Ft. from rotor</th>
<th>Weight of soil in lbs.</th>
<th>Work done</th>
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**Plow Depth**
- 5" Bottom

**Ground Speed**
- 1st Gear

**Rotor to Power Takeoff Speed Ratio** 2:1

**Ground Speed**
- 18" Dia. Rotor

**Rotor**
- 18" Bottom
Appendix D.

Test Data of Mounted Reversible Rotary Terracer
Using the 14 Inch Diameter Helical Rotor
and the 18 Inch Wide Flow Bottom. 1952.
## Reversible Rotary Terracer Test

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<th>Weight of soil in lbs.</th>
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<th>Ft. from rotor</th>
<th>Weight of soil in lbs.</th>
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**Plow Depth** _Loose Soil_  

**Ground Speed** _1st Gear_  

**Reversible Bottom**  

**Mounted on Model 8N Ford Tractor**
### Reversible Rotary Terracer Test

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Plow Depth: Loose Soil  
Reversible Bottom  
Ground Speed: 1st Gear  
14\text{"} Dia. Rotor  

Mounted on Model 3\text{M} Ford Tractor
Appendix E.

Detail Drawings of Parts for Reversible Rotary Terracer.
Figure 53. LIFT BAIL WELDED ASSEMBLY

Dwg. No. 2-101

Part No. 1040 STEEL SEAMLESS TUBING

Part No. 2-101

Part No. 3-102

Description

UNIT

1/2" x 3/8" WALL THK X 26 1/2"

1040 STEEL SEAMLESS TUBING

2-1/8" OD x 3/8" WALL THK X 26 1/2"
Figure 54. BAIL LIFT LINK
Figure 55. BAIL LIFT SIDE STANDARD

- Drill hole 1 1/32" diameter at 2 3/4 R.
- Drill hole 3 1/2" diameter at 2" R.
- Dimensions: 16 1/4" and 17 1/4".
Figure 56. TORQUE TUBE ATTACHMENT BAND

- 1/2" -
- 3/4" -
- 3/4" -
- 1 3/4" R -
- 2 3/4" R -

8"

DWG. NO. 1-103
TABLE OF PARTS

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<td>SHAFT</td>
</tr>
<tr>
<td>1-106</td>
<td>SPACER</td>
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<tr>
<td>2-102-5</td>
<td>ATTACHMENT LOBE</td>
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<tr>
<td>2-102</td>
<td>BRACE-1/4&quot;x1/2&quot;x1040 carbon steel</td>
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</table>

PTO DRIVE MOUNTING BRACKET ASSEMBLY

Figure 57.
Figure 58. PLATE-PTO MOUNTING BRACKET

DRILL & REAM
HOLE 1.000±0.010

DRILL 2 HOLES
13/32" DIA.

DWG. NO. 1-104

9.500±0.100

1/2"

43/4"

9 1/2"

12 3/4"

-3 1/4"
Figure 59. ATTACHING LOBE

DRILL HOLE
25/32" DIA

1/2"

5"

2 1/4"

7"

DWG. NO. 1-105
Figure 60. SPACER

DWG. NO. 1-106

DRILL & REAM
HOLE 1.000 ± .000

2 1/2"
Figure 61. BOLT

THREAD 1" NF

CHAMFER 5/32 x 45°

CHAMFER 3/32 x 45°

1 1/2"

5 1/2"

DWG. NO. 1-107
**Figure 62. TOP LINK YOKE**

### Table of Parts

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### Instructions

- **Arc Weld**: All welds are arc bead unless specified.
- **Flush Bend**: Arc weld.
- **One hole 1.000 +0.010**: Drill before assembly.
- **Fillet Arc Weld**: Hole TO -0.010. Drill & Ream.

---

**Top Link Yoke**