INTRODUCTION

Since the development of wooden plows tillage has been done by animal-drawn, occasionally man-drawn implements and finally by the modern plows. Although the essential features of a plow such as stabilising sole, moldboard, plow share, standard, coulter are more than two thousand years old, the real development has taken place only in the last two centuries.

A new chapter in the history of the plow began when nearly 100 years ago the animal drawn plow was partly replaced by the steam powered plow. In Europe, the steam powered plow had always been important only on the big estates. More recently the tractor drawn, mounted or semi-mounted plow is used most generally.

The problem that has been considered is whether the plow is the right implement for the tractor or not. From the viewpoint of its development it is a drawn implement; but the tractor engine can do more than pull. It has a relatively low efficiency considering the power transmission between tires and soil.

Under favourable soil conditions, the efficiency can be maintained at approximately 70%. Under unfavourable soil conditions this, however, goes down to below 40%, if one does not take special precautions to prevent it. On the average the power transmission efficiency between the tires and soil is about 60-65%.

Many farmers, rotary-tiller manufacturers and engineers have thought about the problem of how to transmit the rotary motion of the engine directly to the implement. Of all the possibilities which have been followed, rotary-tilling received most attention.

With a rotary-tiller, pulverizing of the soil results whereas a plow produces big clods. This rigorous breaking of soil can be advantageous because in a single operation the seedbed can be prepared. But in general it is disadvantageous. A framework of stable big clods which arise out of plowing gives the soil bigger air pores and prevents compaction of the soil after precipitation. A rotary-tilled soil can quickly lose its structure completely if the particles are not stable. But the introduction of an easily operating multigear drive for the shaft, so that peripheral speed of tines, speed of travel of the tractor and length of cut may be varied independently of another should give the possibility to adapt the breaking of soil to any desired soil condition and purpose of cultivation. Whether it will be economically feasible must be determined.

A complete replacement of the plow by rotary-tillers which was once contemplated is no longer considered seriously. However, within their limits in scope and application, rotary-tillers in many cases are capable of performing useful work in addition to that of plows. This is:

1. The mixing of organic matter and manure into the soil.
2. The preparation of a seedbed for vegetables.
3. The breaking of meadows.
4. Tillage in spring on heavy soils to avoid many after-tillage operations.

Comparing the consumption of power, a rotary-tiller requires on light soil 2.5 times and on a heavy soil 3.5 times the power required by a plow for similar width and depth of cultivation. Taking into account the after-tillage operations, for example harrowing, which are necessary after plowing and not needed when rotary-tilled, the power consumption ratio between the two types of implements becomes better. Ultimately one must consider that the rolling resistance and slip of the tractor consumes 35-45% of the total engine power available when plowing, whereas during rotary-tilling only insignificant transmission-losses through the drive shaft occur. Taking all factors into account the power consumption ratio is about 1:1.5.

The high power requirement of the rotary-tiller may be reduced by a suitable form and arrangement of tools, and by selecting an optimum rpm and an optimum ratio of peripheral speed to travelling speed.

The possibility of influencing the specific energy requirement by the form of tools is shown in figures 1 and 2. The specific energy is the energy in ft lbs per cu ft of rotary-tilled soil. On the left in figure 1 the influence of individual tool width on specific energy is illustrated. The wider the tool, the less the specific energy requirement. On the right the benefit of slower speed is shown.

In figure 2 the influence of radius of curvature of the tool on the specific energy requirement is shown. The cutting energy of a 55 mm wide tool with a radius of curvature 15 mm is on the average 25% greater than that of the same tool with 30 mm radius of curvature. This experiment was repeated on soils of different density and the result was found to be exactly the same.

To the designer one problem is that the angular distance between consecutively striking tools must always be equal and that the angular distance between adjoining tools must be as large as possible to avoid clogging. Also important is that the tools on the left and right of the longitudinal axis must strike the soil approximately in symmetry, so that no moment is originated in longitudinal or vertical axis, which results in vibrations.

Basically the higher power requirement of rotary tillers compared to plows, is due to:

1. The high cutting velocity of the tools and the resultant high acceleration imparted to soil particles.
2. The considerably larger cutting surface compared to moldboard plows.
The peripheral velocity of rotary tillers lies between 12 and 22 fps, whereas the plowing velocity at present lies between 4 and 5.3 fps. A measure of acceleration energy imparted to soil is the specific acceleration work per cu ft of soil. Figure 3 illustrates acceleration energy in ft lbs per cu ft of soil (as ordinate) depending on the tool velocity (as abscissa). It is concluded that the soil obtains a velocity of 40-70% of the tool velocity. To understand this a factor \( z = 0.4 - 0.7 \) is introduced. Therefore the acceleration energy (work done in accelerating the soil) imparted to the soil by the tool will lie between these two limits. This process of acceleration has friction losses. These additional friction losses are taken into account through an efficiency factor \( \eta = 0.5 \). It is known from other measurements and considerations that the additional energy losses in friction and compaction caused by acceleration forces are nearly the same as the acceleration energy imparted to soil by tools. The acceleration forces from rotary-tillers as a result of high tool velocity may be as high as 12 times those of tractor plows and 50 times those of animal drawn plows. The specific acceleration energy with rotary-tillers is as large as the total specific energy expended by plows on light soils. With plows at 5.5 fps the acceleration energy amounts to only about 4% of the total energy requirement, whereas with rotary-tillers at 15 fps it amounts to about 35%.

The second reason for higher energy requirement of rotary-tillers over plows is the difference in cutting surface. Figure 4 illustrates the relation of cutting surfaces in sq ft per cu ft of tilled soil as ordinate and the tool width as abscissae. The working depth of plow 1 or the analogous bite length of rotary-tiller tools la is used as a parameter. The bites cut by rotary-tillers are much smaller than a plow-furrow slice cross section and in addition they have a bigger cutting surface by reason of their cycloid form. A plow using a furrow depth of 8 inches and a furrow width of 14 inches has a specific cutting surface of 2.3 ft per cu ft of soil. A rotary-tiller of 2 inch length of cut and 4 inch width of cut has a specific cutting surface of 15 sq ft per cu ft of soil or about 7 times that of the comparison plow. Thus it is clear why rotary-tillers have a higher energy requirement.

**ROTARY DIGGER**

In cases where intensive tillage is not needed, consideration is being given to a less intensive breaking and cutting of the soil with low energy consumption by working with slowly rotating implements. It is desirable to obtain a similar type of clod and the same mixing and turning of soil as in the case of the moldboard plow. A rotary digger implement which operates with relatively small peripheral velocities, cuts big bites out of the soil and turns the soil by rotating the tool about its own axis at the end of their respective cuts has been developed in Holland. The mechanism of this operation is arranged in a hollow shaft. This digger works with a relatively favourable power consumption.

The rotary-digger tool has a larger working width and bite length than that of rotary-tiller. Also the shank of the rotary-digger tool does not cut the soil as in the case of rotary-tiller tool, but the soil is not linearly pulverized. With cutting and shearing it produces individual shear planes and with the laying upside down the bites fall and break up.

Although this implement works similar to a plow, and has a low energy requirement, power is not transmitted by tractor tires but by pto drive. However, when compared to the simple, sturdy, low cost plow it is more sensitive, complex and rather costly.

**OSCILLATING TOOLS**

Another development is the application of oscillating tools for tillage. The draft requirement can be reduced compared to rigid tools. Experiments were carried out to determine what frequencies, amplitudes and swinging directions will result in minimum draft, and the power necessary to produce such oscillations.

The draft of the swinging tools can be reduced up to 25% of that of the same rigid tools. On the other hand a considerable amount of energy is required to produce these oscillations. Favourable ratios result if one is satisfied with a reduction of draft by 50% when a relatively low power is required for oscillations.

Besides reducing the draft the oscillating tools crumble the soil much better, and this may be of advantage for seedbed-preparation and also for ridging the field for potatoes. However, considering only energy relationship oscillating tools bring no advantage, for more power than that saved by reduction in draft is required through the pto to produce the oscillations. Such implements are also sensitive to stones. Therefore the design must be so laid out that violent impact is not transmitted to the mechanism which produces the oscillatory motion.

**POWERED DISCS**

A different approach is to transmit the engine power through the pto to rotate the disc of a vertical disc plow. If the total energy requirement of power driven disc is compared with that of freely rotating discs it appears that there is actually a reduction in draft in the former case. This reduction increases as the ratio of disc peripheral velocity to the plowing velocity becomes greater. However the necessary input power to the discs increases with disc peripheral velocity progressively. It is not advantageous to increase the peripheral speed to more than 1.3 to 1.5 times the forward speed. Then it is possible to reduce the drawbar pull by about 30% whereas the total power increases to 120%. By further increasing the disc peripheral velocity to two times, one can reduce the draft to a half, but then the total power requirement increases to 170%. Unfortunately with increased peripheral speeds the side and vertical forces become large for the above discs. In view of the high
A further use for this procedure would be to compare the operation of one treater with others using the same chemical, or to compare the distribution of different chemicals through any one treater.

REFERENCES


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power requirement and the relatively low reduction in draft of the power driven rotating disc compared to the freely rotating discs, the difficulties involved in design and high costs are not justified.

MOLDBOARD PLOW

Considering tillage implements which diverge from the traditional plow, it appears that all these can only be supplementary to the moldboard plow but cannot replace it at present even if importance of rotary-tilling is increasing. In any case, research should not be neglected in the further development of the moldboard plow. This research should follow two patterns:

1. Development in construction of plows.

2. Development of moldboards for higher speeds.

The plow development is marked by the replacement of trailed plows by mounted plows and also recently by the semi-mounted plows. Meanwhile in Germany, certain standard forms of mounted plows were developed. These are the standard one-way plow, the turn-about plow and the quarter turn-about plow with three point linkage.

Much design work has been done in the development of automatic arrangements for controlling furrow depth. Starting from the Ferguson Patents the so called draft control and position control were developed. Another solution was successfully used by Hanomag in Germany by feeling the surface of the soil with a guide wheel that controls the furrow depth through the tractor hydraulic system.

In a theoretical study on semi-mounted plows from the author in 1953 the following features were proposed:

1. Ability to swing about a vertical axis.

2. Steering mechanism for the furrow wheel.

3. Delayed lifting of the rear end of the plow. At that time there was no suitable tractor in Germany with the necessary hydraulic arrangement to use 4 to 8 bottom semi-mounted plows. Meanwhile these plows were developed by several manufacturers in North America.

In addition to the development of the mounted plows, some work has been done on development of new moldboard shapes for higher speed. As the average tractor power increases the field capacity of plows also increases. It is believed that by increasing engine powers especially with reduced weight per unit of power gradually brings higher plowing speeds. At higher speeds the conventional bodies tend to transport the soil too fast to the side and therefore require more energy. It is therefore necessary to develop high speed plow bodies, which produce more or less similar furrow and breaking of soil as a conventional body does. Considering the future developments in tractor powers in the next 10 or 15 years, plowing speeds of 6.5 mph on light soils and 5 mph on heavy soils are possible to achieve.

In addition to the problem of developing suitable bodies for the higher speeds expected in the near future the problem of the betterment of travelling comfort of tractors by suitable seats and spring-suspensions will require attention. It is necessary to limit the vibrations and accelerations so that the driver can work at least for 8 hrs/day and that this work is not hindered and that his health is not affected after driving for many years.

SUMMARY

The plow will remain the basic tillage implement in European agriculture for some years to come. In Russia on vast areas and in North America on exclusively big farms heavy tractors of more than 200 HP and up to 10 tons of weight may be used to pull mounted and semi-mounted plows having 10 or more bottoms. In the Middle-and-West European agriculture a relatively light tractor with a relatively high engine power will dominate. This tractor will be equipped with mounted one-way or turn-about-plows.

The furrow depth and the turning of plows at the end of each run will be automatically controlled. With the increasing engine power the speeds of these plows will be gradually increased first to 5 mph and then to 6.5 mph. By combination of implements and operations including plowing, seeding, addition of fertilizer, herbicides and insecticides production costs may be reduced.

For soils which do not scour well moldboards coated with plastic having an unusually low friction coefficient may be used. It will be a question of the price-durability relation of teflon sheets if this material will be used on other soils too. In addition to tillage by plows, rotary-tillers have occupied a certain position in their utilization for some soil conditions. It can not be determined whether this utilization can still further be developed by using slowly running rotary-diggers.

This development of soil tillage equipment is not yet finished. Modern tillage implements has relieved the farmer from hard manual work, reduced the time required for tillage to one-tenth. This time will be lowered still further.