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STUDY OF TILLAGE EQUIPMENT
FOR USE WITH TRACTORS IN INDIA

by 6808

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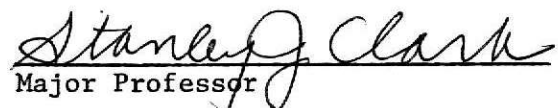
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INTRODUCTION

The use of tractor power in Indian agriculture has been steadily increasing despite several obstacles (ISAE news, July 1969). Although bullocks are still used largely by small farmers, the trend in favor of mechanization is noticeable in the country. With this slow but gradual interest of Indian farmers in Tractor operation, the next logical step would be to make a judicious choice of soil-working implements.

There have been, in fact, three basic reasons for the slow rate of mechanization in Indian Agriculture. The primary reason has been the availability of inexpensive labor in the past, the daily wage being lower than \$2.00, for an unskilled farm worker; this led to greater manual operations being performed, rather than switching to power operated machinery, where total man-hours needed are kept at a minimum. It has however to be noted that the labor costs have been rising every year by six to seven percent (Season and crop report, 1966), and in due course of time, the cost of labor is bound to become a considerable factor. The second reason that has discouraged rapid farm mechanization in India has been the high cost of fuel; the cost of diesel in India being the equivalent of 45 cents per gallon, is about three times as much as it is here, while gasoline at 60 cents to 65 cents per gallon is also comparatively expensive. In this context, shedding light on the power requirements for different methods of tillage, assumes special significance. The third reason has been the operation of small acreages by a vast number of individual farmers, thereby making it economically unfeasible to own and use expensive machinery. In spite of this general fact, there are thousands of farms that are large enough where ownership and operation of farm machinery and equipment has

been logical and economically sound.

All the tillage implements that have been in use so far with the tractors there, are essentially of the conventional drag type; there are however a few small two-wheel type power tillers being introduced in scattered parts of the country and plans are underway for manufacturing tractor p.t.o. operated rotary tillers in India during 1971 (Vertannes, 1970). In view of these facts, this report is intended to make a study of tillage and tillage machinery in the area of seedbed preparation, and to compare the conventional implements with rotary tillage equipment.

The 1968 reference annual on India puts the total cropped area at 395,250,000 acres of which the leading crop is rice with 88,995,000 acres under cultivation, followed by 45,002,500 acres of sorghum, and 32,837,500 acres of wheat. All other miscellaneous crops add up to the remaining 228,415,000 acres of cropped land in the country. From the above figures, it is clear that rice production is a major aspect of Indian agriculture, and it is of special interest to study the applicability of rotary tillage in this important area. Besides the three major crops mentioned above, others grown in India include millets, corn, pulses, and vegetables.

OBJECTIVES

The objectives of this report are primarily three-fold:

1. To study and explain the proper functions a tillage machine is expected to perform;
2. To survey the seedbed preparation implements available here, that are suitable to Indian conditions; and
3. Finally, to compare the various aspects of rotary tillage equipment against the conventional seedbed preparation implements.

Keeping in view the size of the presently available tractors in India, it is intended to suggest the suitable implements, both rotary and conventional, for preparing the necessary seedbeds. Also, a comparison between the two discrete systems is contemplated wherein among other things, the effects on various factors like soil structure, pulverization, clod size, soil mixing characteristics and yields will be considered. In view of the differences in power requirements for the two methods of tillage, a discussion from an economic stand-point will also be made.

It is but logical to include in the next chapters, a look at the use of tractors in India and then to discuss exactly what proper tillage and good seedbeds mean, before finally delving into the main subject of tillage implements.

PRESENT DAY TRACTOR FARMING IN INDIA

Most of the tractors used in India in the period prior to 1958 were imported models, but from the data available, there is an indication of an increasing trend in the number of tractors that have been produced in the past decade (ISAE News, July 1969).

In 1961-62, there were only 880 tractors manufactured there, of which 199 were the 26/27 H.P. Eicher make, and 681 were Massey Ferguson models of 35 H.P. output. In comparison to this total figure of 880 tractors manufactured in 1961-62, the corresponding figure for 1968-69 was as high as 15,466. There has been an addition of three other makes between 1961 and 1968, namely International Harvester model B-275 (34/35 H.P.), Hindusthan tractors (35 and 50 H.P. models) and Escort tractors of 27, 37, and 47 H.P. In all, over 50,000 tractors were produced and sold in India in the past ten years alone. Apart from these major makes that have been either manufactured or assembled in India, there have been a few imports too. Most, if not all the available tractors there, use diesel for fuel. A majority of the tractors in operation are of 35 H.P. capacity or smaller. It might be mentioned though, that plans are underway for manufacture of a new 50 H.P. Ford tractor in India from 1971 which would add another 6,000 units annually to the present output (India News, 1970).

It has been shown by Balis (1963) that tractor operation in India is comparatively cheaper than the use of bullock power, in spite of the high cost of fuel. His estimates show a cost of Re. 0.865 (11.5 cents) per H.P. - hr. for bullock power, against a value of Re. 0.5 (6.7 cents) per H.P. - hr. for tractor power, while electrical energy was the least expensive at a Re. 0.2 (2.7 cents) value. Apart from the final cost analysis, the

important facility afforded by tractors is being able to complete the needed farm operations in a reasonable length of time and at the right part of the season. It might be appropriate to quote the published figures of 44.0 hours per acre for bullocks as against 16.0 hours per acre for a 10 H.P. tractor for performing the four main operations of tillage, planting, threshing and haulage in a corn and wheat growing area (Balis, 1968). It could be expected too, with little doubt, that more powerful tractors could further cut down on the time needed for the various operations. In a survey conducted among Indian farmers in July 1967, it was found that more than half the tractor owners had gross annual incomes no greater than \$13,000 approximately, and that their individual farms were 100 acres or smaller (ISAE News, October 1969). The above figures are stated to support the fact that if the size of the farm is sufficiently large, the use of tractors will definitely be more profitable than using animal power. Also, it is clear from the above, that there is a great popular demand for tractor power and hence, it is logical to discuss in this report the necessary implements for the same.

Tractors in India are used for all the usual tillage and cultivating jobs, and also for haulage when trailers are hitched to transport materials and produce. In some instances, the pulley of the tractor is used for irrigation purposes too. Also, in certain cases, particularly for rice, the unthreshed produce is laid on a clean surface, and tractors are run over it to thresh out the grain. This is, at best, a crude method to thresh the grain, but in view of not being able to afford combines for the job, this method is resorted to, as the next best. Other manual operations are performed later to separate the grain from the chaff.

Due to the comparatively limited number of tractors being used in scattered parts of the country, there is sometimes a problem of finding parts and service when urgently needed. This might work as a deterrent against buying tractors, but in final analysis however, it should be noted that this is a chain reaction and the fastest way to solve this problem would be to go into greater use of mechanized equipment. The increased use of tractors allow the dealers to establish an improved maintenance service, and more centers for distribution of parts.

PROPER FUNCTIONS OF TILLAGE EQUIPMENT

Primary and secondary tillage operations are practised by farmers to suit their individual needs and their particular crop and soil conditions. Even though we cannot establish a definite set of performance specifications that a tillage implement must meet, Bainer, et al. (1955) have set forth in a general way, the following purposes of tillage:

1. To control weeds by performing tillage operations as and when needed;
 2. To develop a desirable soil structure for a seedbed or a rootbed; a granular or crumb structure is desirable to allow rapid infiltration and good retention of rainfall, to provide adequate air capacity and exchange within the soil, and to minimize resistance to root penetration. A good seedbed is generally considered to imply finer particles and greater firmness in the vicinity of the seeds;
 3. To facilitate the placement of surface residues; thorough mixing of trash is desirable from the tilth and decomposition standpoints, whereas retention of trash in the top layers reduces erosion;
 4. To minimize soil erosion by following such practices as contour tillage, listing, and proper placement of trash;
 5. To prepare land for irrigation;
 6. To smooth or otherwise prepare the soil surface for harvesting operations;
 7. To incorporate and mix fertilizers or soil amendments into the soil.
- It might be well to discuss in detail some of the topics that are related to seedbed preparation, and the effect of tillage on soil temperatures and microbial activity.

The seedbed requirements for satisfactory germination, as stated by Richey, et al. (1961) are:

1. Sufficient warmth;
2. Sufficient air;
3. Adequate moisture; and
4. A layer of soil between the seed and the surface which can be penetrated by the sprout of the particular seed.

Seeds vary widely in their soil moisture requirements for germination, and also in the energy of their sprouts. Corn and potatoes have low moisture requirement and high sprouting energies; they can hence be planted fairly deep and in relatively loose soil. Grass seeds must be planted close to the surface because they have low sprout energy and also require more moisture (ibid.); if planted deep enough to stay moist, they may not be able to penetrate to the surface. A light mulch is valuable in securing a stand of grass, because it retains moisture but does not offer resistance to the sprouts. In general, a fine firm seedbed favors germination but may crust over excessively and is often not the most desirable rootbed.

Good soil tilth is the most important rootbed factor. Tilth is usually defined as the degree of aggregation of the soil. Ideal tilth is secured when the soil is aggregated into crumblike particles that allow adequate access of air and water and are not easily broken down by rainfall.

Pulverization is essential to the action of the air on every soil particle (Bond, 1925). The attainment of a fine tilth is therefore necessary for proper aeration of the soil. Pulverization has an important role in the management of soil moisture. If heavy soils are tilled when too damp, soil particles will fail to separate as desired and they will cohere more firmly

on drying. Plowing the land when too dry also makes it difficult to prepare a good seedbed, because the soil breaks up in large clods. Unless these clods are broken down by alternate wetting and drying, or by freezing and thawing, it is difficult, if not impossible to prepare a good seedbed. Plowing the soil when too dry is not as destructive to soil structure as plowing when the soil is too wet (Browning, 1950). Working the soil at optimum moisture tends to favor granulation. Studies indicate that the best condition for tillage would be when the soil moisture content is slightly below field capacity (ibid.). Soil moisture tension is normally between $1/10$ and $1/3$ atmosphere when the soil is at field capacity. Sandy soils tend to be near $1/10$ atm. at field capacity, while clays tend toward $1/3$ atm. (Israelsen and Hensen, 1967). Organic soils can be tilled when they are comparatively wetter than other soils, because they have a stable structure. It is probable that different tillage implements require somewhat different soil moisture contents for optimum operation.

Pulverization has other benefits too; weeds cannot be drawn out of the soil unless it has been so refined, that it falls away from them. Fertilizers cannot be thoroughly mixed with soil unless it is sufficiently granulated, and seeds cannot be drilled regularly at a uniform depth nor covered with a suitable protective layer of soil, unless the seedbed has been properly comminuted. Superficial pulverization leaving the under part of the seedbed cloddy, is very unfavorable to crop growth. The clods bridge open spaces under the seed, thus preventing rise of moisture into the region of the seed and the young roots. Until the clods have crumbled down, as they ultimately do, the soil lacks the firmness which is requisite for proper growth.

All farm crops require a certain amount of firmness in the root zone along with adequate aeration through the soil particles. Bond (1925), has stated that the two primary reasons for firmness are:

1. To provide sufficient and suitable anchorage for the plants; and
2. For the feeding organs--the root hairs--to apply themselves closely against the soil particles, in order to draw upon the film of moisture surrounding them.

From the foregoing, it follows that equipment used for secondary tillage should produce proper pulverization, and at the same time provide adequate seedbed firmness.

Roots of growing plants need air. This is demonstrated by plant behavior when the water table is too near the surface. Under such conditions, many crops will not survive, because the water will exclude air from the soil. It is also known that oxygen is needed for the germination of certain seeds (Davidson, 1947). There must also be air in the soil for growth and development of helpful soil bacteria that thrive on the organic matter in the soil. These bacteria stimulate decomposition, making more plant food available. In like manner, the soil must be open and contain sufficient air, in order that the nitrification processes are promoted. To promote this aeration, it would appear that soils should be suitably broken up; first by primary tillage tools like the moldboard plow or the disk plow, and later by seedbed preparation implements like the disk harrow and the spring tooth harrow, so as to permit the free passage and continuous circulation of air in the soil.

It has been established that the more plants per acre there are, and the more vigorously they grow, the more of oxygen that is required, and that normal growth of most crops is possible only when the oxygen concentration

exceeds at least ten per cent (Kohnke, 1968). The ability of rice to thrive under flooding is attributed however, to the presence of interconnecting air chambers in the cortex, which are able to supply oxygen to the roots, so long as the top remains exposed to the atmosphere. It might be appropriate here to refer to the Atterberg's plastic limits. The lower Atterberg limit is the minimum moisture condition at which the soil continues to be plastic and the upper limit signifies that moisture content at which the water films become so thick that cohesion is decreased. An increase in the percentage of clay causes both plastic limits to be higher on the moisture scale; it should be remembered that compression of the soil increases rapidly with moisture content above that of the lower plastic limit (Baver, 1956).

The moisture content of the soil is very important for the reason that the yield of crops is largely dependent upon the available moisture (Davidson, 1947). Tillage influences soil, first by making it easy for water to enter the soil, and second, by increasing the number of soil particles which hold moisture on their surface. Davidson (1947), gives the value as ten to twelve inches of moisture that is needed for the proper growth of grain crops, during the fast growing season. Since the rainfall in many localities seldom reaches this amount during the growing period, it is necessary to store moisture in the soil in advance of the growing season. The depth and thoroughness of tillage will determine to a very large extent, the amount of water that may be stored in the soil. In the case of irrigated agriculture however, all the water needed for crop growth is not stored in the root zone, but is transported and applied as and when required. Nevertheless, tillage equipment is used in such instances too, for suitable preparation

of the land for irrigation. Soil moisture from rainfall or irrigation settles the soil after an opening and breaking up process brought about by tillage.

Before leaving the topic of aeration and moisture content in the soil, it might be well to mention that bulk density is a fairly good measurement of space available in the soil for holding air and water. It measures the denseness of the soil although it does not give us an idea of the size and distribution of its pores. Thus, it is a practical measure of the general physical condition of the soil mass, and comparison of bulk density values before and after tillage, convey to us the estimate of the increase in porosity of the soil layers.

Soil temperature affects plant growth and can be modified by tillage practices (Lovely, et al., 1960). Tillage affects soil temperature through its effects on compaction, moisture, surface roughness, configuration, and shading and reflection by plant residues or other material on the surface. An adjustment of the roughness and moisture content modify both absorption of heat and radiation and conduction of heat energy away from the soil. The moisture tension level at the soil surface is an important factor in determining the rate of evaporation or condensation; these in turn, cool or heat the soil (Kohnke, 1968). Soil temperature requirements of plants vary with the species. It also must be assumed that the soil temperature requirements of plants vary with the stage of growth. Anderson and Kemper (1964), found that corn yields were approximately doubled by a ten degrees centigrade rise in temperature above twenty degrees centigrade. Tillage practices may not be able to make a large contribution to an increase or decrease in soil temperatures, in contrast to the ambient climate, but what little is possible through such means, might prove helpful in the early

stages of plant development.

The microbial activity in the soil influences the availability of nutrients and the soil structure. Tillage can affect markedly, the microbial activity through its effect on the interrelationships of soil moisture, soil temperature and aeration, and also through the placement of plant residues (Lovely, et al., 1960). This means that the systems of seedbed preparation that create a warm and moist condition early in the season usually are best suited both for microbial activity and growth of higher plants. In places where the lowest temperatures reached do not have any detrimental effect on the crop in question, this special emphasis for creating warm conditions in the seedbed might not be relevant.

The question of how deep to till, has been asked many times. Cooper (1967) has said that if a very dense layer is within the surface eighteen inches, it should be broken up to allow water, air and roots to penetrate the soil profile more easily. After this deep plowing is done and the secondary tillage operations are performed, care should be taken to see that tractor tires do not travel over the area where the rows will be planted, so that a tendency favoring recompaction is eliminated.

In the light of all that has been mentioned so far with reference to the subject of this report, we could conclude this chapter with the following general statements about how a good seedbed actually should be, after all the tillage operations are performed. We should eventually have a seedbed such that the fine grainlike particles or aggregates trickle through the fingers when a handful of the soil is picked up. It should feel loose and mellow, but not too loose for good germination. It should be well supplied with readily available organic matter and should contain enough large

pores for proper aeration and moisture movement. Turner (1948), however has cautioned against very large air spaces in the subsurface layers because they break contact with the untilled soil and this might be unfavorable to the capillary rise of moisture. The above characteristics of a well-prepared seedbed should extend at least to a depth of six inches, and in addition, favorable air, water and nutrient proportions should be created throughout the entire root zone.

With the foregoing material as background, the next chapter envisages the specific discussion of tillage implements that tend to create a favorable seedbed and the necessary conditions for optimum growth of crops.

SEEDBED PREPARATION IMPLEMENTS FOR TRACTORS IN INDIA

Conventional Equipment:

Many factors affect the selection and operation of implements in the several steps necessary for the preparation of seedbeds. Turner (1948) states some of them as follows:

1. Type of soil;
2. Kind of crop to be grown;
3. Moisture conditions;
4. Soil erosion from wind and water;
5. Season of the year;
6. Power available;
7. Residue left on the land;
8. Insect pests; and
9. Previous crop grown on the land.

In general, secondary tillage in India involves one or more diskings followed by passes with spring-tooth or spike-tooth harrows, and the further use of rollers or packers if deemed necessary.

The disk harrow is adapted to a wide variety of uses in many types of farming practices. It can be used before plowing to cut up vegetable matter that may be on the surface, such as cornstalks, cotton stalks and weeds, and also after plowing, to pulverize the soil and put it in better tilth for the reception of the seed. There are two distinct classes of disk harrows:

1. Trailing; and
2. Mounted.

The trailing disk harrows are hitched to the drawbar and pulled, whereas the mounted types are used with the three-point hitch of the tractor.

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Both the ~~trailing~~ and mounted disk harrows are further classified as single action, ~~double~~ action or tandem, and offset types. The single action harrows consist of ~~two~~ gangs of disks placed end to end. They throw the soil in opposite ~~directions~~ and range in width from 4 to 12 feet. Double action harrows are also ~~called~~ tandem because a set of two gangs follows behind the front gangs, and is ~~arranged~~ so that disks on the front gangs throw soil in one direction (usually outward) and the disks on the rear gangs throw soil in the opposite ~~direction~~. The double action disk harrows range in their width of cut from 5 to 15 feet. The third type can be operated in an offset position in relation to the tractor, and a change in hitching can cause the harrow to run to ~~either~~ the right or the left of the tractor. It is possible with the offset disk harrow therefore to operate for instance, under limbs of trees in an orchard, and such other places. The width of cut for offset disk harrows ranges from 4 1/2 to 30 feet.

Plate I indicates the three types of disk harrows and the International Harvester's tandem disk harrow model 23 A. This harrow shown in Plate I, Fig. 2, is a ~~trailing~~ type and has a cutting width of 5 feet. It has sixteen disks, the ~~total~~ weight being around 500 pounds, the exact figure depending on whether the disks chosen have a diameter of 14 or 16 inches. This implement is well suited to India since a vast majority of Indian tractors are of the 25 to 35 H.P. capacity, or under. Most, if not all, have the three-point hitch and the drawbar for attachment of implements. The model 23 A has the front and rear gangs connected by a sturdy steel center-frame in place of the connecting bars commonly used on tandem disk harrows. This frame provides a center pivot point which increases the flexibility of the harrow, making it easy to turn and maneuver. When backing, the front and rear frames contact to make a compact unit, and it is

EXPLANATION OF PLATE I

Fig. 1. Three types of disk harrows according to gang arrangement.

Fig. 2. The I-H five-foot tandem disk harrow, model 23 A, shown
equipped with regular tractor power angling. Angle setting
is rope-controlled from the tractor seat.

PLATE I

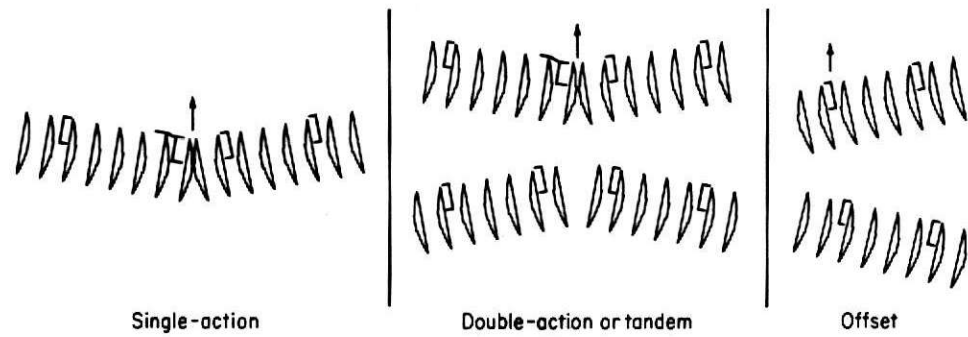


Fig. 1

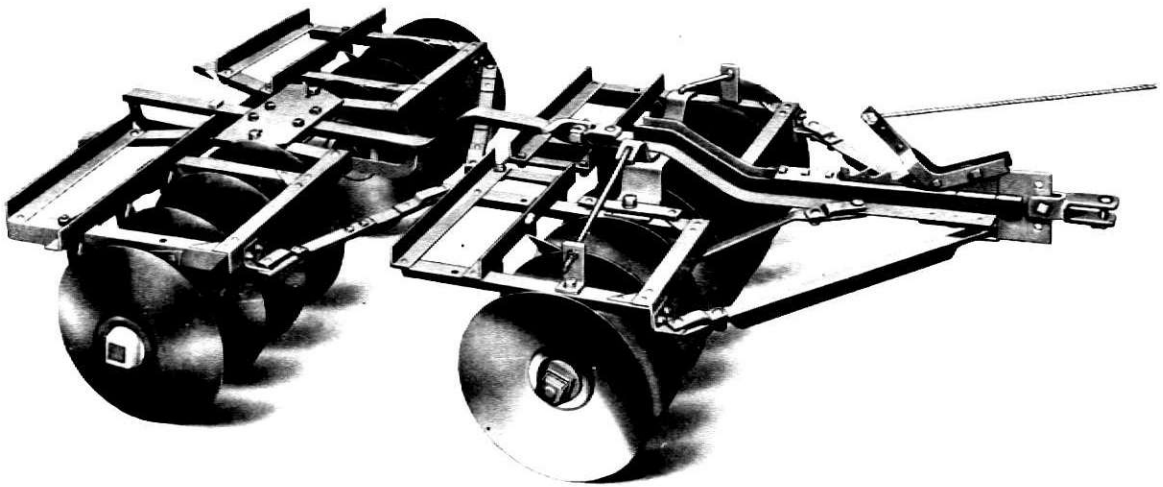


Fig. 2

claimed that this will eliminate buckling and jackknifing. There is also a choice of notched disks that are available, if large amounts of residue has to be cut through. The 23 A is regularly equipped with a power angling device for controlling the angle of the gangs. Forward motion of the tractor angles the gangs and backing the tractor straightens them. A gang adjustment bar and lever, rope controlled from the tractor seat, permits adjusting the angle setting from 0 to 20 degrees. Of course, the tractor manufacturers in India have various types of disk harrows matched for the tractors they put out, and the model 23 A is referred to here, only from the aspect of its weight and the power requirement of the tractors that is needed to operate it.

In general, disks vary in diameter from 12 to 20 inches and are spaced six to ten inches apart; also, the plain regular disk usually has about 2 inches of concavity to 20 inches diameter (Stone and Gulvin, 1957). Having smaller disks or spacing disks wide apart, permit greater penetration in the soil. It should be noted however that smaller disks work deeper and result in heavier draft than larger disks (Bond, 1925). Wide spacing is preferable for use in gumbo bottomland where cornstalks are to be cut. Turner (1948) has stated that heavily manured lands, cottonland, cover crops, as well as western orchards and truck crop areas usually respond better to disking when disks are far apart.

Increasing the cutting angle of the disks also increases penetration, but Stone and Gulvin (1957), caution that if the angle is increased much above 20 degrees, they will tend to drag and cease to roll, thus tremendously increasing draft and also giving poorer results. Other means of increasing penetration would be to add weights or exert hydraulic forces or both,

particularly when the disk harrow is not equipped with transport and depth-regulating wheels.

Stone and Gulvin (1957), have suggested the following method to check if the disk harrow presently being used is light enough for the tractor operating it. With the throttle open half-way initially, the tractor should immediately pick up speed when the throttle is quickly opened. If the response is sluggish, release some of the draft by dangling or removing weights. In a properly adjusted disk harrow, the rear disks should cut midway between the ridges of the front disks (Turner, 1948).

The spring tooth harrow is used to break the soil crust and pull weed roots to the surface where the sun dries and destroys them; it also tends to bring clods to the surface. By stirring the soil, it aerates and warms it and thus prepares it for seeding. As in the case of disk harrows, there are two general types of spring tooth harrows:

1. The lift type; and
2. The trailing type.

The teeth of the harrow are made from high carbon spring steel, which has been forged and rolled to shape, and then oil tempered (Stone and Gulvin, 1957). The teeth are usually $1\frac{3}{4}$ inches wide and $\frac{5}{16}$ or $\frac{3}{8}$ inch thick. The first spring tooth harrow is said to have been made in 1871 (Bond, 1925). Many improvements and modifications on the spring tooth harrow have been made since then. There are broadly four kinds of spring teeth used in these harrows, depending upon the job that needs to be done. They are known as regular, quack grass, alfalfa, or detachable point teeth. The teeth used for eradicating quack grass are pointed at the working end. This results in deep penetration; roots are torn loose and brought to the surface. The teeth

used for cultivating alfalfa sod are curved similar to the regular teeth, except that at the working end, the teeth are narrowed down considerably and tapered to a pointed edge.

The John Deere HD 2240 Integral spring tooth harrow shown in Plate II, Fig. 1 has two 4-foot sections with depth control levers. This harrow, operated by means of the three-point hitch, should be a satisfactory choice for Indian tractors, particularly since there is an option of seven different types of teeth that are available to suit different purposes. The HD 2240 has extra wide runners and wear shoes that not only last long, but also increase flotation in wet spots. The front wear shoes overlap and shield the front bends of the runner, providing protection at these points of greatest soil abrasion. The levering action of the tooth bars has two advantages; first, it forces the teeth to reach working depth quickly and to drive deep into the soil when set for maximum penetration, and second, it can also provide added lift when the teeth are raised for quick trash release.

A bent spring tooth may be returned to correct shape by heating it to a cherry red color and rebending, using a new tooth as a guide. The original hardness and temper will be maintained if the tooth is allowed to cool slowly on the floor (Stone and Gulvin, 1957). It is best to operate a spring tooth harrow at a fairly low and steady speed for best performance; since it has few moving parts, it needs no lubrication.

The peg tooth harrow or the spike tooth harrow is also used to smooth and level the soil after plowing. It will stir the soil to a depth of two inches or slightly more when appropriately weighted. The sections may range in width from four to six feet and may have 25, 30 or 35 teeth. Several sections may be either rigid or flexible. The harrow is called rigid when the steel bars have a brace across them at right angles to the tooth bars.

EXPLANATION OF PLATE II

Fig. 1. The John Deere Integral Spring tooth harrow model HD 2240 with two 4-foot sections; shown here with regular heavy duty teeth.

Fig. 2. The John Deere lever flexible spike tooth harrow, 5½ feet wide, weighing 120 pounds.

PLATE II

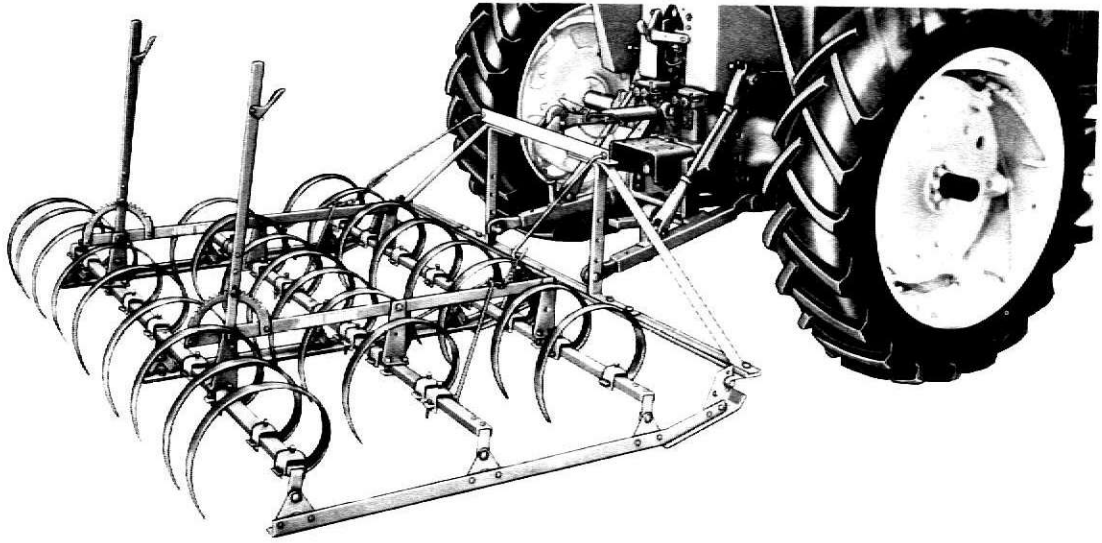


Fig. 1

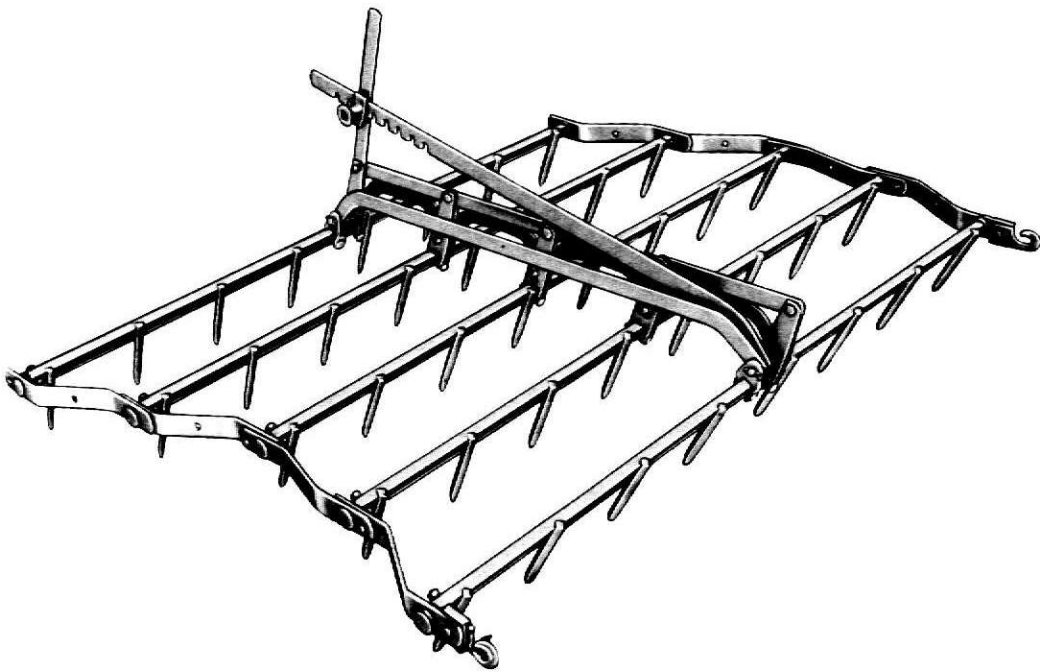


Fig. 2

There are no means of adjustment other than that of adjusting the angle of the teeth. A flexible harrow can be rolled up, as the links between each tooth bar are hinged; it also adjusts itself to uneven ground much better than the rigid harrow. In some designs, the teeth can be reversed after the forward edge has worn down and in others, the harrow as a whole, can be drawn in the reverse direction.

The spike tooth harrow is also an excellent tool for pre-emergence cultivation, to break rainformed crust and destroy small weeds. When used for cultivation, the flexible harrow is pulled in one direction, when the teeth assume a vertical position. For smoothing, it is pulled from the opposite direction and the teeth automatically incline themselves at an angle. The usual spacing is 9 inches apart on five tooth bars, giving approximately a 1.8 inch spacing between tooth marks (Stone and Gulvin, 1957). The high carbon diamond shaped reversible teeth usually measure about $5/8$ inch by $7/8$ inch in their cross-sectional dimensions.

The John Deere lever-flexible spike tooth harrow shown in Plate II, Fig. 2, can be used advantageously as a fully flexible harrow. If desired, the end rails can be bolted rigid, and all the teeth operated at a constant angle that is adjusted by means of the lever. The teeth of this harrow are projection welded to the high carbon U-Beam tooth bars. When the leading edges of the harrow's teeth get dulled after long use, the entire section may be reversed by reversing the draft hooks and the lever ratchet assembly; when not needed, the harrow folds flat for convenient storage.

The coil spring harrow is another implement that could be used for seedbed preparation as well as weed control. It has double torsion-coil spring teeth that work independently of each other. Their flexible action

closes the small sub-surface air pockets, thus helping to preserve soil moisture. The teeth have the advantage of not clogging in wet or trashy conditions, besides being efficient even in stony and rough soils. The International Harvester model 8 coil spring harrow is provided with draft brackets, permitting it to be pulled from either side. Pulling from one end causes the teeth to operate in a vertical position and pulling from the other end, causes them to work at a 25-degree slant; thus, the harrow can be quickly adjusted to different field conditions. The I-H harrow has 5 angle steel tooth bars clamped to 2 angle steel frame members. The double torsion-coil teeth are made of 5/16th inch spring steel; they are 10 inches long and connected to the tooth bars. They are arranged to provide a 1.6 inch tooth mark spacing. The weight of the harrow, being as low as 100 pounds per section, is ideally suited for smaller tractors.

Land rollers and pulverizers are available in several sizes and types. The basic purpose of all of them is to crush clods and finish preparing the seedbed. The judicious choice of a pulverizer has to be based on a knowledge of the soil type we are working with, and the power output of the tractor being used. In general, the average weight of a smooth roller would be around 100 pounds per foot of width. The draft varies from roller to roller and from soil to soil, but as an average value, it may be from 25 to 30 pounds per 100 pounds of weight (Davidson, 1947). Although a roller with a larger diameter requires less draft, the smaller rollers are generally more effective as clod crushers than the larger ones. Since they sink deeper, they present a greater part of their spherical surface to the clods and act on them through a greater distance (Bond, 1925).

When there is a large amount of crop residue on the surface in a fluffy

condition, the rotary hoe operated in reverse, (the rounded or back part of the points striking the soil first), is useful in packing the residue into the surface soil. The rotary hoe is commonly recommended for cultivating purposes, and can also be used for seedbed preparation, without the need for extra rolling equipment. It might be appropriate to mention here about the mulch planter developed and experimented with, by the International Harvester company (Poynor, 1950). This machine, for corn, was designed to prepare the seedbed, fertilize, and plant in a once-over operation. The seedbed was firmed by a set of 4 rotary hoes trailing behind 2 sweeps working at depths of two inches and eight inches respectively. The yields with this set-up were even better than other conventionally treated plots, although the increase in yields is attributed more to the extra fertilizer that was applied in this operation, rather than the mechanical treatment.

In conclusion, it could be stated that the final choice of implements is dictated by the particular conditions of soil, climate, crop, and other factors present in an individual circumstance. The implements dealt with in this chapter, give, but just a general coverage of seedbed preparation tools normally used, and the list is, by no means, exhaustive or comprehensive.

Rotary Tillage Equipment:

The rotary tiller is an implement which is furnished with a rotating shaft on which L-shaped or C-shaped blades are mounted. In the tractor models, the shaft is driven through a clutch and gear train from the power take-off of the tractor. The discussion of general concepts of rotary tillage is contemplated for the following part of this chapter, and a detailed comparison between conventional implements and rotary equipment will be made in the next one.

The angle of impact of the rotary tiller blades is such that the forward edge cuts into the soil with a slicing action and excavates a crescent shaped slice of earth; the size of the slice depends on the speed of the rotary shaft and the forward speed of the tractor. The blade next following in sequence then slices another section. The action of the blades does not exert a direct vertical force; therefore, the rotary tiller does not tend to cause a plow-pan (Howard, F-201). The rotating shaft and the blades, in effect, push the tractor forward so that the required tractive effort by the rear wheels of the tractor is greatly reduced; this in turn, reduces the tractor wheel compaction of the soil. The end result of practical significance would be that the soil can be worked at a given moisture content with greater ease by a rotary-tiller than with conventional drag equipment. This is of special importance in rice production where all the puddling is done at a moisture content around the liquid limit. The Howard Rotavator Company has a special model - K unit for rice production, which uses curved C-blades and wide flotation skids; these skids enable the machine to ride the rough terrain of levees and cope with the ruts caused by the tractor wheels cutting into the wet clay soil. The C-blade was introduced in 1962

by Howard Rotavators; it was designed to handle situations such as heavy and wet buck-shot or gumbo clay containing a heavy growth of grass and stubble. It has been found that due to its self-cleaning qualities and a general open design, it was possible to travel faster with the model K than was previously possible with blades of a different design (Howard, F-282). The power requirements of the model K were understandably less; the C-blades are also claimed to be less critical of rotor speeds than other shapes.

The vegetable residue after the harvest should be returned to the soil, so that it can decay into humus and improve soil structure. The rotary tiller is quite capable of performing this function by thoroughly mixing residue with the tilled soil. It cuts and chops the residue and buries it evenly throughout the entire cultivation depth, while leaving some chopped residue on the surface to protect against wind and water erosion (Howard, F-201). It should however be noted at this stage that with rotary tillage, weed and grass control is more difficult, because the residues are not completely buried under the surface as with a plow. As a matter of fact, weed and grass germination is stimulated because of the fine pulverization of the surface (Richey, et al., 1961). If an effective herbicide is available, this problem of excessive weed infestation could probably be solved without much difficulty. In some cases, a rapid run over the soil with rotary cultivator set to rotate at a high speed and just skimming the surface, followed by a period of dry weather, kills most of the weeds previously growing on it. To secure rapid and complete decay into humus, more nitrogen than usual should be applied during rotavation (Howard, F-201). The bacterial growth demands nitrogen and will extract this from the crop residues, if additional nitrogen is not supplied. It is worth mentioning here that the nitrogen fixed by the

bacteria does not suffer from leaching as do many nitrogenous fertilizers (ibid.).

The rotary tiller has been criticized at times for working the soil more than what is desirable for maintaining soil structure. The introduction of the selectatilt gearbox has been beneficial in this regard; the rotor speed can be quickly changed in the field to appropriately suit the soil and moisture conditions present. The transmission to the selectatilt gearbox is by means of a universal drive shaft from the power take-off of the tractor. The rotor speeds for a 540 r.p.m. power take-off source, range from 125 to 215 r.p.m. whereas, for a PTO rating of 1000 r.p.m., the rotor can be operated at either 155 or 180 r.p.m. (Howard, F-382). With increased rotor speed, the fineness of the prepared seedbed would be high, and so a low to medium speed should result in a satisfactory job. There are various tillage widths available, ranging from 28 inches to 80 inches. The P-series of the Howard Rotavators with smaller widths should be suitable for Indian tractors, since they are made for tractors up to 37 PTO H.P. They are available in four working widths from 40 to 70 inches. Either L-blades or C-blades can be used and the unit can be mounted both centrally, as well as offset to the right. The P-40 model shown in Plate III, Figure 1, weighs 578 pounds and the models in this series can be adjusted to a maximum depth of eight inches by means of a depth control wheel. Plate III, Fig. 2 indicates the C-blades that would be suitable for wet land puddling in rice production. The American-Marietta Tillit rotary mixer is specifically made to suit the International Harvester's B-275 tractors that are widely used in India. Like the others, it is attached to the three point hitch and operated by the power take-off. There are also other makes of rotary tillers that can be used with the

EXPLANATION OF PLATE III

Fig. 1. The Howard rotary tiller model P-40. It is suitable for tractors up to 35 H.P.

Fig. 2. The C-blades shown are designed for operation in heavy and wet soils.

PLATE III

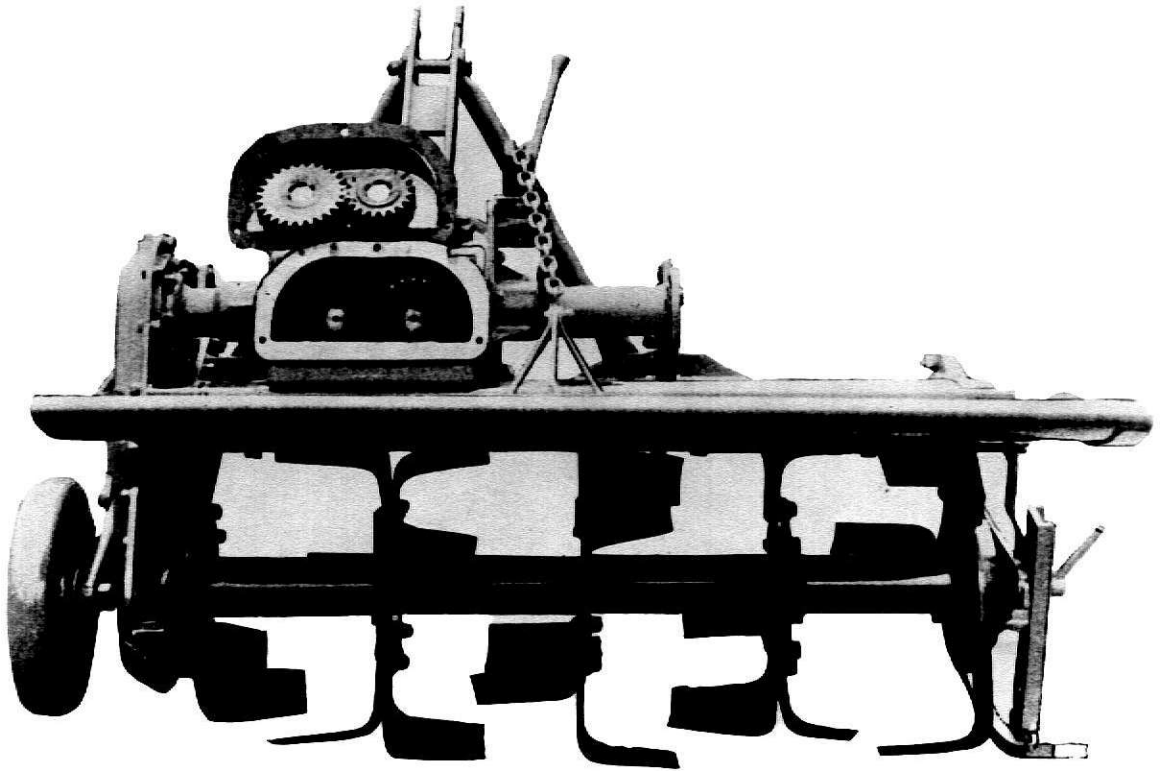


Fig. 1

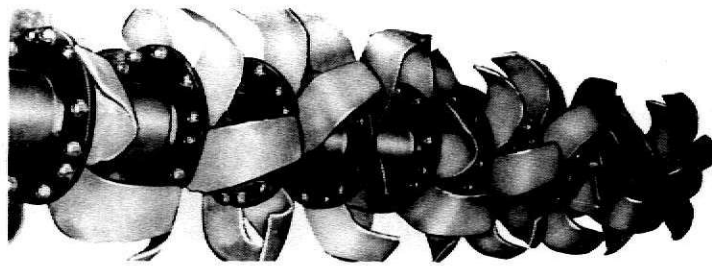


Fig. 2

smaller tractors in India; although there may be a slight difference in design between them, the basic function and mode of working is essentially same.

It is generally agreed that the power requirements for operating rotary equipment are higher than for other implements. In the next chapter, a detailed discussion and comparison of power requirements will be made, but suffice it to say here, that although the power requirement is higher, the number of passes needed to prepare the seedbed are fewer with the rotary tiller than with drag equipment. Excessive power consumption results because soil requires more force for pulverization by impact, than by lifting or crushing as is done by conventional tillage tools (Richey, et al., 1961). The power requirements are extremely variable and a 36-inch width is available even for 25 HP tractors. The ideal objective is to produce only the required degree of pulverization. This can be done with common tillage tools in general dry-land farming, whereas rotary tillage may be advisable when the land has to be worked in a wet condition.

COMPARATIVE STUDY OF CONVENTIONAL AND ROTARY EQUIPMENT

Effects on various soil properties and yields:

Rotary tilling, at times, might be more beneficial than conventional tillage, but there are various other factors involved that have to be considered before any generalized statement of preference could be made.

Some of the advantages of rotary tillage over conventional drag equipment, as stated in "Rotavation" (1970), are given below and will be considered in greater detail later on. With rotary tillage, it is claimed that better soil structure results; the above publication further states that with fewer passes required with a rotary tiller, there is less compaction of the soil layers, and a better retention of moisture in the root zone. With less compaction, the soil could be expected to warm up faster in the spring resulting in earlier germination. Browning (1950), says however that rotary tillage can be expected to break down soil structure rather than improve it; this could be particularly true when there is no means of adjusting the rotor speed to the soil in which it is working. When the rotor is operated at the optimum speeds by the use of a gear box or by other means, there should be less damage done to soil structure. The correct speed at which the rotor should be operated depends on the individual soil, and at what moisture content it is being worked.

About 1930, experiments were performed at Rothamstead, England where rotary tillage was performed without any other preliminary work on the soil following the harvest of a crop. This was compared with plowing followed by harrowing and other methods of tillage to complete the preparation of the seedbed (Wolfe, 1958). It was found that with the rotary tiller, only one operation was required to produce the proper tilth, whereas following

plowing, as many as six harrowings were sometimes necessary. Tilth, as will be recalled from the chapter on tillage, is the important rootbed factor and represents the degree of aggregation of the soil particles. The work done at King's College in 1955 showed further, that the tilth produced by the rotary tillers were generally finer on the surface than in the deeper layers (ibid.).

In an experiment performed by the National Institute of Agricultural Engineering in England (Wolfe, 1958), individual plots were tilled for vegetable crops by the same methods for six years. At the end of this period, penetrometer measurements indicated that there was a compacted layer below the maximum depth of plowing, but not in the case of rotary tillage. Measurements of the sizes of the aggregates in cultivated depths of the soil however, showed similar structures following rotary cultivation and plowing.

In contrast to the above results, another experiment on structure (Kozlova, 1965), revealed a definite improvement in the structure of the derno podzolic sandy loam cultivated soil in the rotary tilled plot compared to the plow plots. It was also found that there were no clods greater than 30 mm in the rotary tilled soil, and the percentage weight of the fraction less than 0.25 mm in diameter, was only slightly greater than in plowed soil. It will be appropriate here to refer also, to other work done in the area of clod-size comparison. An 80 cm diameter rotor, operating at a depth of 18-20 cm in a clay loam soil was compared with plowing and harrowing; it was observed that while 98.1 percent of the clods obtained by rotary tillaging were under 50 mm in diameter, only 58.1 percent of the clods were in this category after plowing and harrowing (Chernenkov, et al., 1962). From the various references noted above, the following summarized statements can be

made. The soil structure resulting from rotary tillage is generally comparable to, or better than that from conventional tillage, provided the rotor speeds are properly controlled. The soil tilth obtained with just one pass of the rotary tiller is as good as that obtained from several harrowings after plowing. There is a possible formation of a plow-pan below the maximum depth of plowing, but in the experiments performed, no such evidence was found when a rotary tiller was used. Finally, it was observed that with rotary tillage, the sizes of about 98 percent of the resulting clods were under fifty mm in diameter, whereas after plowing and harrowing, there were only about 58 percent of the clods that fell in this desirable category. It should, however, be noted that a clay loam soil was used in this experiment, and different results could be expected from other soils.

The incorporation characteristics of a rotary tiller have been found to be very much better than those obtained with conventional tools. In U.S.D.A. experiments at Beltsville, Maryland, a series of tillage operations were carried out using a radioactive phosphorous solution as a tracer material (Howard, F-382). The field was first plowed and a fine seedbed prepared by disking and harrowing. The solution was then sprayed over the soil, ahead of the various tillage tools which included the disk harrow, the spring-tooth harrow, and the rotary tiller. After the various mixing operations, samples were taken in three 2-inch layers. One pass of the rotary tiller resulted in 51% of the residue being in the top 2 inches of the soil, 38% in the layer from 2 to 4 inches, and 11% from 4 to 6 inches. In comparison to this, the corresponding values obtained after disking twice were 69%, 30%, and 1%. The complete table of comparison for different mechanical treatments, is shown in Plate IV, Fig. 1. Another experiment made at the

EXPLANATION OF PLATE IV

- Fig. 1. The chart indicates the incorporation characteristics in the soil layers, resulting from different tillage treatments.
- Fig. 2. The sorghum grains in the figures represent the respective mixing abilities of various tillage tools, when used on ground that had not been previously prepared.

PLATE IV

SOIL SURFACE	ROTAVATE	ROTAVATE TWICE	DISK TWICE	DISK	SPRING TOOTH HARROW
2" DEEP	51%	34%	69%	78%	84%
4" DEEP	38%	35%	30%	22%	16%
6" DEEP	11%	31%	1%	0%	0%

Fig. 1

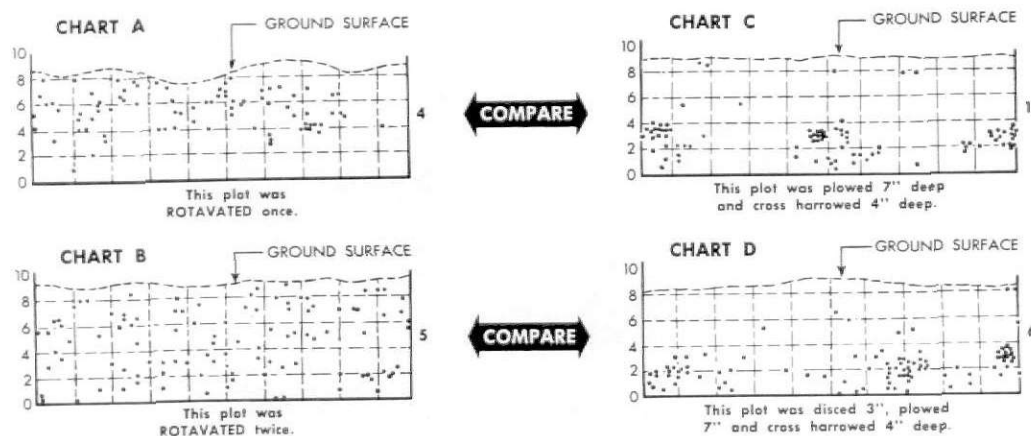


Fig. 2

same location involved soil that had not been previously prepared. Sorghum grains were broadcast directly ahead of the various tillage tools and worked into the soil. Figure 2 of Plate IV indicates the distribution of the sorghum grains in the soil layers after using different tillage tools and clear evidence can be seen in favor of rotary tillage. The knowledge about incorporation characteristics is important to the farmer, because they are an indication of how well the tillage tools can mix not only the residues, but also the pre-plant fertilizers and insecticides.

As mentioned earlier in the chapter on rotary tillage, there is a problem of weed infestation when the practice of rotary tillage is adopted. Unless there is some inexpensive way of destroying the weeds by chemicals or other means, the crop yields are bound to be affected. In fact, Willard, et al., (1956), have expressed dissatisfaction over rotary tillage because it gave rise to a high rate of weed growth with consequent decrease in yields. They have stated that the only time the yields from rotary tilled land were better than conventionally prepared land was when there was no heavy rain at any time after the land was prepared. Under these conditions, the soil remained loose and "fluffed up" for the entire season. If there are rains, the rotary tilled soil becomes compact, resulting in a low water infiltration rate (Willard, et al., 1956).

The effect of various methods of tillage on the yields of several crops on Brookston Clay Loam were measured by Cook and Peikert in 1950. Amongst others, the plow followed by normal secondary tillage was compared with rotary tillage and a plow packer. This plow packer consisted of a series of cast wheels, an axle and an appropriate frame. It was pulled behind the conventional plow. Their results indicated that the once-over soil preparation made possible by the plow packer was helpful in minimizing cost of

seedbed preparation, while still maintaining yields comparable with those obtained by other tillage means. They also observed that in cases where the crops followed sod, weed control was much easier when the sod was completely turned under, than when it was mixed with surface soil. Similar experiments in Ohio, Michigan and New York, comparing different tillage treatments, have shown that seedbeds can be prepared by a single operation using a plow and a section of a packer or reversed rotary hoe for smoothing. Yields of corn, oats, beans and beets have been as good as those obtained with conventional preparation. This resulted in a considerable cost reduction for ground preparation (Richey, et al., 1961). Apparently, the gain in porosity and maintenance of surface aggregation has offset any loss due to decreased germination. Surprisingly, weed seed germination has been less on these plots than on plots that have been prepared in the traditional manner, possibly because the coarse surface structure does not favor germination of small weed seeds. In many of the experiments, difficulty was encountered in killing a sod by any method other than plowing (ibid.).

In preparing land for rice, however, a different situation exists. More about this will be mentioned in the ensuing section dealing with power requirements. Even in the case of rice, no significant difference in yields has been observed between land prepared by the plow or rotary tiller. This is probably because, in the experiments, both operations were followed by a harrowing pass to produce the necessary puddled condition (Khan, 1971).

Power requirements and economic considerations:

The figures obtained from various sources indicate that the approximate energy cost for a tractor operated rotary tiller working 9 inches deep, is 50 H.P.-hours per acre (Wolfe, 1958). For comparison with this value, measurements on conventional plowing and the appropriate seedbed operations result in a cost of 19.6 H.P.-hours per acre. It should be noted though, that with drag implements, there are greater drive losses than with rotary tools. It was estimated that although the power requirement appears high for rotary tillage, the fuel needed per acre was not different from that for conventional tools (ibid.). This was probably due to the fewer passes needed with the rotary tiller for preparing the seedbed. A 40 H.P. tractor with a 4-foot rotary tiller needed 3.5 gallons of fuel per acre, which was the same as that required for standard operations of plowing followed by two diskings and one harrowing. When a tractor of sufficient capacity is being used anyway with conventional tools, changing over to a rotary implement would, in effect, increase the efficiency of operation. The factor of excessive power requirement would come into focus only when the presently used tractors are not sufficient to serve the power needs of the rotary tillers. Since satisfactory rotary tillers are being made for 35 H.P. tractors, the excessive power requirement for operating them should not serve as a deterrent against their use.

It was also observed that while operating a 4-foot rotary tiller, the tractor was working at maximum load and covering about one acre per hour. The three operations of plowing, disking and harrowing amounted to a cumulative figure of 1.35 hours per acre (ibid.). These values indicate that rotary tillage could very well be one means of completing the seedbed

preparation in a shorter time than by conventional means. As mentioned elsewhere, the element of timeliness becomes an important consideration in certain situations.

With a rotary tiller, it has been observed that the man or machine hours and the fuel needed per acre run approximately the same, irrespective of whether the tillage is in dry land or in flooded soils (Johnson, 1967). While a rotary tiller gives a beneficial negative draft or a forward push to the tractor, tools like a moldboard plow or a disk harrow, increase the draft tremendously in wet land preparation for rice (IRRI Annual report, 1963). Also, while puddling, the wet soil sticks to the disk harrow making the job less satisfactory and also increasing the time needed to scour the implement. It was clearly stated in the 1963 annual report of the International Rice Research Institute, that standard tractors are not very effective on flooded soils because of the spinning of the rubber wheels. The only two ways of improving performance according to the report are, by either using a rotary tiller that tends to push the tractor, or by using cage wheels to give additional flotation and traction. Best performance could result in preparing flooded soils, when the rotary tiller is used with a tractor equipped with cage wheels. Assuming that a harrowing operation will follow both rotary and moldboard plowing, it would be well to compare these two methods for rice production. Stout (1966), has given the values of 180-350 HP-hours per hectare and 8.2-10 man hours per hectare for moldboard plowing as against roughly 140 HP-hours and 4 man-hours per hectare with rotary tillage. These values further reinforce one's inclination to favor rotary tillage for rice production.

Having analyzed the two methods of tillage regarding seedbed preparation and yields, it is appropriate to consider them now, from the standpoint

of the costs involved.

Holler and Arsdall (1966), have compared costs for producing crops like corn and soybeans in Central Illinois. Their study includes both pre-plant operations and subsequent cultivation. They figured an initial investment of \$14,270.00 for conventional implements whereas rotary equipment was slightly higher, with an initial investment of \$14,615.00. The annual overhead (fixed) costs were therefore slightly higher for rotary tools and the tractors needed with them. Their values were given as \$2,374.00 for rotary, compared to \$2,295.00 for standard tools.

The field capacity analysis shown in Appendix I indicates a maximum of 100 acres of dry land or 60 acres of wet land that can be tilled with one tractor (in a 2-week period). On that basis, the values arrived at in Appendix II, indicate an annual fixed cost per acre of \$6.59 with rotary tools and \$6.28 with conventional tools for dry land tillage. For preparing wet land, the corresponding figures are \$10.40 for rotary and \$10.47 for conventional.

The fuel costs for dry land tillage, as quoted by Holler and Arsdall, are \$1.77 per acre with rotary tools and \$1.86 per acre with conventional tools. It is also known that fuel costs in case of rotary tillage are about the same, irrespective of whether the soil is worked in a dry or a wet state (Johnson, 1967). Exact data is not available for estimating the fuel costs with conventional tools when working in wet land; however, from certain values put forth as energy requirements, this cost could be placed roughly at over \$2.00 per acre. All the above values are subject to change under Indian conditions, but their relative significance to each other will not be materially altered in any area.

Since labor is not a major cost item in India, we can, for our present purposes, omit this factor in comparing costs. On the basis of the findings of Holler and Arsdall, we could say that the machinery costs per acre would not be significantly different between rotary and conventional tools. It could however be expected that fuel costs would be higher when tillage is done with conventional tools in wet land. When implements are referred to as conventional, they may or may not be exactly the same units used by Holler and Arsdall, and hence, their figures, at best, can serve only as guidelines.

The primary tillage at the International Rice Research Institute in Philippines is followed by a harrowing operation, (Khan, 1971); it is probable that the model K of Howards might eliminate the need for secondary tillage. If this is so, a rice farmer would do well to invest in a rotary tiller that costs about \$900.00 than to select a moldboard plow and a disk harrow, that together can amount to about \$800.00. When the choice between just a plow and a rotary tiller is to be made, a rice farmer might still select the latter if he has sufficient land under production, because of the additional advantages of the rotary tiller. The initial price differential between a moldboard plow and a rotary tiller may be in the order of one acre of his land, and he is in ultimate analysis, the best judge of the situation. Besides the land preparation aspect, the rotary tiller is very helpful in dealing with the post-harvest residues and might prove better than drag equipment. Of course, in normal cases where crops are grown on dry land, it might be best to adopt some suitable drag type minimum tillage practice rather than selecting a rotary or a conventional tillage practice.

SUMMARY AND CONCLUSIONS

Minimum tillage reduces the time and costs involved in seedbed preparation; several sources have shown that the yields obtained with minimum tillage practices have been comparable to those obtained by rotary and conventional methods.

In normal dry-land farming, a packer consisting of a series of cast wheels could be directly attached to the rear of the plow; other similar once-over methods, if acceptable, should be preferred over rotary tillage or a series of conventional operations.

There is no single minimum tillage practice that is universally acceptable. Hence, the one to be adopted should first be tried to see if it suits the local crop and soil conditions. In cases where minimum tillage is not feasible, either rotary tillage or the traditional means of plowing, disking and harrowing is practised. With reference to this aspect, a comparison between rotary and conventional methods of tillage has been made in an attempt to determine their respective merits.

The soil structure resulting from rotary tillage has been comparable to, or better than that obtained from conventional practices. The soil tilth obtained after one pass of the rotary tiller has been found to be as good as that resulting from several harrowings after plowing; the sizes of clods resulting from rotary tillage were also more favorable than those obtained by other means. Compacted layers were found below the maximum depth of plowing, but there was no such evidence under rotary tillage. It was also observed that the rotary tiller had superior incorporation characteristics compared to drag implements, where pre-plant fertilizers or insecticides were mixed with the soil or crop residues had to be turned in. In contrast to the

foregoing benefits, weed growth has been found to be more troublesome on rotary tilled plots than on plots treated conventionally. The yields have not been very satisfactory from rotary cultivated land due to this excessive weed growth, particularly when the weeds were not controllable through inexpensive means.

For dry land tillage, the fuel cost per acre and the annual tractor and machinery costs are about the same for both methods, although a higher fuel cost may occur with conventional tools when working in flooded soils. If a sufficiently powerful tractor is available, rotary tillage has a decided advantage over all other methods of tillage for rice production. The rotary tiller working directly behind the tractor, creates a negative draft and in effect, pushes the tractor forward in the wet or flooded soil. In addition to this advantage, less time is wasted for scouring because the clay soil does not stick to the rotor blades as it does to other tools like a moldboard or a disk. In the production of rice, it has been found that the man-hours and the H.P.-hours needed per hectare are definitely less with rotary tillage than with other means and that the yields from rotary tillage have not been significantly different from those obtained by other means.

It should be reiterated here that although an appropriate drag type minimum tillage practice may be advisable for dry land crops, rotary tillage provides a definite improvement over conventional tools, when the soil has to be worked in a wet or flooded condition. In either case, a gradual modification of the traditional tillage practices in India, could very well prove to be a beneficial change.

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BIBLIOGRAPHY

1. American-Marietta Company.
'Tillit'--Rotary mixer information pamphlet. Milwaukee, Wisconsin, July 1961.
2. Anderson, W. B. and W. D. Kemper.
Corn growth as affected by aggregate stability, soil temperature and soil moisture. Agron. J., 1964, 56:453-456.
3. Bainer, Roy, R. A. Kepner and E. L. Barger.
Principles of farm machinery. John Wiley & Sons, Inc., 1955, pp. 139-140.
4. Balis, John.
An estimate of the power required for intensive cultivation. Ag. Inputs Development Division, USAID, New Delhi, 1968, p. 4.
5. Balis, John.
The workability of bullocks. The Agricultural Engineer, Annual publication of the Agril. Engg. Society, Allahabad Agril. Institute, Allahabad, India, 1963-64, pp. 15-19.
6. Bharat Krishak Samaj Yearbook.
(Yearbook of Indian National Farmers Union). A-1, Nizamuddin West, New Delhi, 14, India, September 1964, pp. 480-512.
7. Bond, James Ryding and Sir John Russell.
Farm implements and machinery. Ernest Benn Ltd., 8, Bouverie Street, E. C. 4, London, 1925, pp. 4-6, 69-81.
8. Browning, G. M.
Principles of soil physics in relation to tillage. Ag. Engg., July 1950, pp. 341-344.
9. Chernenkov, A. D., I. G. Osmakov and N. S. Karavyanski.
Rotary cultivation of heavy soil for for row crops. Vestn. Slekhoz. Nauki, 7 (8), 1962, (R), pp. 54-59..
10. Cook, R. L. and F. W. Peikert.
Comparison of tillage implements. Ag. Engg., May 1950, pp. 211-214.
11. Cooper, A. W.
Pamper your plants with proper tillage. Cotton, March 1967, p. 18.
12. Culpin, C.
Farm machinery. Crosby Lockwood & Son, Ltd., 39, Thurloe Street, S. W. 7, London, 1947, pp. 128-140.
13. Davidson, J. Brownlee.
Agricultural machinery. John Wiley & Sons, Inc., New York, 1931,

pp. 28, 36, 38-44.

14. Davidson, J. Brownlee.
Agricultural machinery. John Wiley & Sons, Inc., New York, sixth printing, 1947, pp. 81-83, 138.
15. Giles, G. W.
Opportunities for advancing agricultural mechanization in India and South-East Asia. The Agricultural Engineer, Annual publication of the Agril. Engg. Society, Allahabad Agril. Institute, Allahabad, India, 1963-64, pp. 5-14.
16. Handbook of Agriculture.
Indian Council of Agricultural Research, Revised Edition, January 1966, pp. 45-55, 563-602.
17. Hine, H. J.
Rotary cultivation. Agriculture, London, 1962, 69(4):160-164.
18. Hirning, Harvey J. and Dale O. Hull.
You can lower tillage costs. Hoard's Dairyman, February 10, 1970, p. 134.
19. Holler, Douglas A. and Roy N. Van Arsdall.
Alternate systems of tillage for Illinois grain farms. Dept. of Ag. Econ., Univ. of Illinois, Ag. Experiment Station, January 1966.
20. Howard Rotavator Company.
Newsheets: F-201, F-282 and F-382, Harvard, Illinois.
21. Howard Rotavator Company.
Rotavation. Booklet, 1970, pp. 4-7.
22. Hulburt, W. C. and R. G. Menzel.
Soil mixing characteristics of tillage implements. Ag. Engg., 1953, pp. 702-708.
23. India, A Reference Annual.
Compiled by the Research and Reference Division, Ministry of Information and Broadcasting, Gov't. of India, 1968, pp. 221-222.
24. Indian Embassy.
India News. Washington D. C., September 11, 1970.
25. Indian Society of Agricultural Engineers.
Indian Society of Agricultural Engineers News. July 1969, Vol. 3, No. 2.
26. Indian Society of Agricultural Engineers.
Indian Society of Agricultural Engineers News. October 1969, Vol. 3, No. 3.

27. International Harvester.
Tillage tools sub-section. General Sales Catalog, 1962.
28. Israelsen, Orson W. & Vaughn E. Hansen.
Irrigation principles and practices. John Wiley & Sons, Inc.,
February 1967, p. 164.
29. John Deere Agricultural Sales Manual.
Tillage equipment section. March 1961.
30. Johnson, Lloyd.
Land preparation. IRRI Saturday Seminar, September 2, 1967.
31. Khan, Amir U.
Head, Ag. Engg. Dept., International Rice Research Institute,
Philippines, personal communication to author by letter of
January 15, 1971.
32. Kohnke, Helmut.
Soil physics. McGraw Hill, 1968, pp. 41-52, 160-162, 189-191.
33. Kozlova, L. D., I. B. Revut and N. M. Fomichev.
Effectiveness of rotary tillage before sowing. Dokl. Akad. S.-Kh.
Nauk., 1965, (R), No. 4:23-26.
34. Lovely, W. G., G. R. Free and W. E. Larson.
Preparing the seedbed. Power to Produce, U. S. Dept. of Ag.
Yearbook, 1960, pp. 136-142.
35. Mecolly, H. F.
Agricultural mechanization in East Asia. Ag. Engg., 1965,
46:26-27.
36. Musgrave, R. B., P. J. Ziverman and S. R. Aldrich.
Plow-planting of corn. Ag. Engg., September 1955, pp. 593-594.
37. Poynor, R. R.
An experimental mulch planter. Ag. Engg., October 1950, pp. 509-
510.
38. Pradhan, S. N.
Chapter on Ag. Engg. Technical Report of the Central Rice Research
Institute, Cuttack, India, 1965, pp. 215-228.
39. Richey, C. B., Paul Jacobson and Carl W. Hall.
Ag. Engineers' Handbook. McGraw Hill, 1961, pp. 125-127.
40. Richharia, R. H., and S. N. Pradhan.
Mechanized puddling of rice lands. Paper presented at the con-
ference on Mechanization and the World's Rice, Massey Ferguson
School, Warwickshire, England, September-October 1966.

41. Season and Crop Report.
Bureau of Economic Statistics, Gov't. of Andhra Pradesh
Hyderabad, India, 1965-66.
42. Smith, H. P.
Farm machinery and equipment. McGraw Hill, third edition, 1948,
pp. 136-139.
43. Smith, H. P.
Farm machinery and equipment. McGraw Hill, fifth edition, 1965,
pp. 154-164.
44. Stone, Archie A. and Harold E. Gulvin.
Machines for power farming. John Wiley & Sons, Inc. 1957,
pp. 228-260.
45. Stout, B. A.
Equipment for rice production. FAO paper No. 84 of the United
Nations, Rome, 1966, pp. 24-27.
46. Turner, Arthur W. and Elmer J. Johnson.
Machines for the farm, ranch and plantation. McGraw Hill, 1948,
pp. 28-29, 60-68.
47. U. S. Steel Corporation.
New steels for the agricultural equipment designer.
48. Vaugh, Mason.
Problems in Indian agriculture. AE 1945, p. 294.
49. Vertannes, G. W. S.
Personal communication to author on behalf of Howard Rotavator
Company, Ltd., Essex, England, November 1970.
50. Willard, C. J., G. S. Taylor and W. H. Johnson.
Tillage principles in preparing land for corn. Ohio Agr. Expt.
Station Research Circular #30, March 1956.
51. Wolfe, J. S.
Rotary cultivation. Farm Mechanization, August 1958, pp. 294-297.

APPENDIX I

FIELD CAPACITY ANALYSIS

The following formula is used to estimate the field capacities:

Width of swath in feet X M.P.H. = No. of acres covered per 10 hr. day.

DRY LAND TILLAGE:

100 acres to be prepared in two weeks time.

Operation	swath in feet	speed in M.P.H.	acres per 10-hr. day	no. of days needed for operation	
CONVENTIONAL					
TOOLS:					
Plowing	4	3	12	8	
Disking	8	4	32	3	Total of
Spring-tooth	12	4	48	2	15 days
Harrowing	12	4	48	2	(150 hrs.)
ROTARY					
TILLER:					
First pass	4	3	12	8	Total of
Second pass	4	4	16	6	14 days
					(140 hrs.)

WET LAND TILLAGE

60 acres to be prepared in two weeks time.

CONVENTIONAL					
TOOLS:					
Plowing	4	1.5	6	10	Total of
Disking	6	2	12	5	15 days
					(150 hrs.)
ROTARY					
TILLER:					
First pass	4	3	12	5	Total of
Second pass	4	3	12	5	10 days
					(100 hrs.)

For wet land, it is assumed that the field has been plowed dry once earlier in the season when free time was available.

APPENDIX II

Holler and Arsdall (1966), have quoted the annual fixed costs for owning machinery. Their values (including the annual cost for two 40 H.P. tractors) are \$2,374.00 for rotary, compared to \$2,295.00 for conventional tools.

In order to arrive at the cost of using the tractors for only the tillage operations, the following estimate per hour of tractor use is made.

Assumptions: Original price of tractor is \$4,000.00 and the total annual use is for 750 hours.

Fixed costs:

Depreciation.....	\$ 400.00	
Interest on Investment at 6%	120.00	
Taxes, insurance and housing	<u>130.00</u>	
Annual cost of owning tractor (for 750 hrs.)	\$ 650.00	----- I
Fixed cost of tractor per hour = (650/750) =	\$ 0.87	

Estimation of Annual Fixed Costs:

DRY LAND (200 acres)

Rotary tools:

Annual fixed cost of 2 tractors + rotary tools (Holler and Arsdall)	\$2374	
Annual cost of 2 tractors at \$650 each (From I above)	<u>1300</u>	
Annual fixed cost of rotary tools alone	\$1074	----- II
Cost of 280 hours of tractor use with rotary tools at \$0.87 per hour (at the rate of 140 hrs. per tractor, from field capacity analysis)	244	-----III
Adding II and III		
Total fixed cost for 200 acres is	\$1318	
Therefore, total annual fixed cost per acre with rotary tools = (1318/200) =	\$ <u>6.59</u>	

Conventional tools:

Annual fixed cost of 2 tractors + conventional tools (Holler and Arsdall)	\$2295	
Annual fixed cost of 2 tractors at \$650 each, (From I above)	<u>1300</u>	
Annual fixed cost of conventional tools alone	\$ 995	----- IV
Cost of 300 hours of tractor use with conventional tools at \$0.87 per hour (at the rate of 150 hrs per tractor, from field capacity analysis)	262	----- V
Adding IV and V, Total cost for 200 hours is	\$1257	

Therefore, total annual fixed cost per acre
with conventional tools = $(1257/200)$ = \$ 6.28

WET LAND (120 acres)

Rotary tools:

Annual fixed cost of rotary tools alone (From II above)	\$1074	
Cost of 200 hours of tractor use with rotary tools at \$0.87 per hour (at the rate of 100 hrs per tractor, from field capacity analysis)	<u>174</u>	
Total fixed cost for 120 acres	1248	
Therefore, total annual fixed cost per acre with rotary tools = $(1248/120)$ =	\$ <u>10.40</u>	

Conventional tools:

Annual fixed cost of conventional tools alone (From IV above)	\$ 995	
Cost of 300 hours of tractor use with conventional tools at \$0.87 per hour (at the rate of 150 hrs per tractor, from field capacity analysis)	<u>262</u>	
Total fixed cost for 120 acres	1257	
Therefore, total annual fixed cost per acre with conventional tools = $(1257/120)$ =	\$ <u>10.47</u>	

STUDY OF TILLAGE EQUIPMENT
FOR USE WITH TRACTORS IN INDIA

by

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B.Sc., Osmania University, India 1967

AN ABSTRACT OF A MASTER'S REPORT

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The use of farm tractors in India has been steadily increasing, and although the tillage tools so far have been essentially of the drag type, plans are underway for manufacturing rotary tillers in the country starting this year.

In view of the above facts, the intended objectives of this report are primarily three-fold:

1. To study and explain the proper functions a tillage machine is expected to perform;
2. To survey the seedbed preparation implements available here, that are suitable to Indian conditions; and
3. Finally, to compare the various aspects of rotary tillage equipment against the conventional seedbed preparation implements.

Besides other functions, a tillage machine is expected to develop a desirable soil structure for the seedbed and maintain proper tilth in the root zone. It should also facilitate placement of surface residues, and control weeds if necessary. Tillage also influences factors like temperature, aeration porosity, and moisture content in the soil, which are all required in the right proportions for proper growth of crops.

A brief study has been made in this report to suggest some of the available implements here, that could be used advantageously with the smaller tractors in India. Some of the conventional implements discussed in this report include the International Harvester's tandem disk harrow model 23 A, and the John Deere's HD 2240 Integral spring tooth harrow, and the lever flexible spike tooth harrow. In the rotary tools category, the P-series of the Howard Rotavators and the American-Marietta's "Tillit" rotary mixer are suitable for Indian tractors; for rice production however,

the model K of Howards or a similar machine with curved C-blades would be desirable.

The comparative study between rotary equipment and traditional tillage tools revealed the following facts. The soil structure obtained from rotary tillage is generally comparable to, or better than that resulting from conventional tillage, provided the rotor speeds are properly controlled. The soil tilth obtained with just one pass of the rotary tiller is as good as that obtained from several harrowings after plowing. There is a possible formation of a plow pan below the maximum depth of plowing, but no such evidence was found when a rotary tiller was used. In a clay loam soil, the sizes of clods obtained were more favorable from rotary tillage, than from plowing and disking. The incorporation characteristics of a rotary tiller are better than by other means, but the problem of weed infestation has been definitely higher on these plots than on those treated conventionally. This is probably because the rotary tiller does not completely bury the residues under the surface, as is the case with the plow. Due to this excessive weed growth, yields from rotary tillage have not been any better than by other means. Unless there is an inexpensive method of destroying the weeds, this might work as a deterrent against the use of rotary equipment. In the production of rice however, the rotary set-up has a decided advantage over other means of tillage, because the rotary tiller tends to push the tractor forward, thereby greatly reducing the problem of tractor bogging in the flooded soil. It has also been determined that the H.P.-hours and man-hours needed for tillage in the wet paddies are less for rotary, than that required by moldboard plowing and subsequent operations. From the cost analyses available, it is known that although rotary equipment might necessitate a higher initial investment, the machinery costs on a

tillable acre basis are not significantly different from conventional practices. The fuel costs are higher for conventional tools when working in wet soil, but for tillage in dry land, the fuel costs for both systems are approximately the same.

It has been shown by some researchers that certain drag type minimum tillage practices for normal dry land crops have saved considerable time and money involved in seedbed preparation. If the use of a plow-packer or some such similar means is found acceptable for dry land crops, it should, by all means get preference over both rotary and conventional tillage methods. In the case of rice however, it might be best to suggest rotary tillage for maximum benefit.