Soil Tillage in the Tropics and Subtropics

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2.0 IMPLEMENTS FOR PRIMARY TILLAGE

The main purpose of primary tillage is to create sufficient pore volume for absorbing water and air and to allow easy penetration of plant roots by loosening the soil down to the bottom of the arable layer. If the soil is inverted organic matter is deposited at deep levels, weeds are controlled and, under certain conditions, leached fine soil material and nutrients are restored to the surface. Crumbling and mixing are important, especially in areas where the following crop has to be sown shortly afterwards and many (secondary) tillage operations cannot be carried out.

Essentialy, the following implements are available:
- mouldboard plough,
- disc plough,
- chisel plough,
- rotary tiller.

The functions of these implements are compared in Fig. 17.

effect \ implement	mouldboard plough	disc plough	rotary tiller	chisel plough
pulverizing	medium	medium	big	small
loosening	big	medium	medium	big
mixing	small	medium	big	small
inverting	big	medium	small	small

big ▨ medium ⊠ small ☐

Fig. 17. Some effects of primary tillage implements after Heege.

Less common or specialized implements, such as the spading machine, will not be discussed in this chapter. Primary or main tillage operations are required on all soils for each crop or each year.

A benchmark in the history of mankind's development was achieved when the Sumarians invented the sowing technique and the hoe for loosening the soil in Mesopotamia more than 5000 years ago. Some 4000 years ago the Sumarians were able to introduce new forms of livelihood and settlement by using wedge (or ard) ploughs in a regular crop production system. This occured after the domestication of animals (sheep and cattle) and the training of those animals for draught work.

The first hoe was simply a branch used to scratch the soil. With relatively minor improvements this implement has survived in numerous countries (some 70% of all the world's farmers are still using wedge ploughs). This implement, together with a simple wooden leveller, is employed as a standard tool for primary tillage, preparing seedbeds and forming furrows and ridges for sowing and irrigation.

The wedge plough is the most typical and widely-used primary tillage tool in the arid tropics and subtropics. The implement loosens the soil without inverting it, leaves a rough structure and does not completely bury plant residue. Consequently, the tilled surface is less susceptible to erosion. The relatively low draught required is adapted to the prevalent conditions. The heavy seedbed preparation operations usually have to be performed before the rainy season when the draught animals are often weakened by inadequate food supplies during the dry season.

The inverting plough was developed around the early Christian era in the north-western European regions, i.e. in a cool humid climatic zone. The principal advantage of this implement is that it definitely improves weed control. The tillage intensity is also higher. In an experiment 50% of the surface was covered with clods > 50 mm after being tilled with a wedge plough whereas only 15 - 20% of the surface was covered by such clods after being tilled with a mouldboard plough.
The disc plough generally produces less intense and a different quality of tillage than the mouldboard plough but it is more suitable for rougher conditions (soils with roots, boulders or gravel).

The chisel plough may be used instead of the disc or mouldboard plough in many cases. In terms of performance, it is a direct descendant of the hoe.

In contrast, the rotary tiller makes the most of the tractor's power take-off device and is paricularly suitable for intensive mixing of soil and organic matter, as well as for intensive tillage (churning) of the soil itself.

When combined with other operations for increasing production, deep primary tillage usually leads to higher yields with little risk of crop failures. From the economic point of view, however, trials are needed to determine whether maximum yields also provide maximum (cash) returns. The ecological and sociological aspects should also be taken into account.

A note on Subsoiling

The following pages do not examine subsoiling equipment in detail because subsoiling should not be considered as a regular operation but as a special treatment for improving the soil (profile). This operation may be carried out only once or at intervals of several years.
Subsoiling is "Any treatment to loosen soil with narrow tools below the depth of normal tillage without inversion and with a minimum mixing of the soil. This loosening is usually performed by lifting action or other displacement of soil dry enough so that shattering occurs" (SSSA Tillage Terminology, 1978).
In practice, it is difficult to make a clear distinction between chisel ploughing and subsoiling and subsoiling is too often adopted as a regular farming technique. Soil compaction caused by bigger and heavier tractors and equipment is usually given to justify subsoiling operations.

Unfortunately, the very fact that heavy tractors are used may tempt a farmer to buy and use subsoiling equipment.

In many cases the results of subsoilig are scarcely positive and may even be detrimental as regards not only the soil structure but also the financial benefits. The operation requires a high energy consumption and is effective only when there is a genuine hardpan which can be shattered under dry soil conditions. A correctly performed subsoiling operation will have longer-lasting results on heavier soils than on light sandy soils.

Subsoiling operations must be given careful consideration, especially in developing countries where only limited energy and equipment are available. "Under-the-row" subsoiling methods which build a ridge on top of the furrow made by the subsoiler shank have produced positive results in the USA but only under specific weather conditions.

2.0.1 Literature

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2.1 The Mouldboard Plough

2.1.1 Use And Assessment

The mouldboard plough can be used for the following purposes:
- stubble tillage,
- deep inverting tillage,
- mechanical weed control,
- working in organic matter (plant residue, green or cattle manure),
- seedbed preparation,
- wasteland cultivation (reclamation).

The mouldboard plough (Fig. 18) is a typical soil tillage implement in the temperate latitudes; it is not really suitable for the arid tropics and only partially suitable for the humid tropics. Fields tilled with a mouldboard plough are susceptible to wind and water erosion. Much water will be lost by evaporation and the decomposition of organic matter will be accelerated because of the increased aeration and heating of the soil. Even in a temperate climate the decomposition of organic matter resulting from ploughing is estimated at approx. 2 tons/ha/year. A further disadvantage of this plough is its high draught requirement. The risk of smearing the furrow bottom by tractor-wheel slippage is high, specially on wet soils. With irrigated agriculture nutrients may be leached down in the profile by water gifts. A short-body mouldboard plough drawn at low speed is often used when such conditions obtain and weed control is particularly important.

Use of the mouldboard plough is justified only under conditions where - combined with other measures - it will lead to higher yields, without increasing the risk of erosion and where the resultant accelerated decomposition of organic matter can be offset by additional biomass left on the field (roots, plant residue).

Use of the mouldboard plough may also be warranted by the need to control weeds. Factors militating against the use of the mouldboard plough in the tropics and on heavy soils in the subtropics are its limited capacity (ha/hour) and the intensive secondary tillage needed to break up the large hard clods after primary tillage to prepare a seedbed.
When the soil is to be tilled shortly after the rainy period, more effecient equipment is required, such as the chisel plough, disc implements or p.t.o.-driven implements. Fig. 17 compares the functions performed by these implements.
Nevertheless, the plough is a strong simple implement and only a few of its parts are subject to wear and tear.

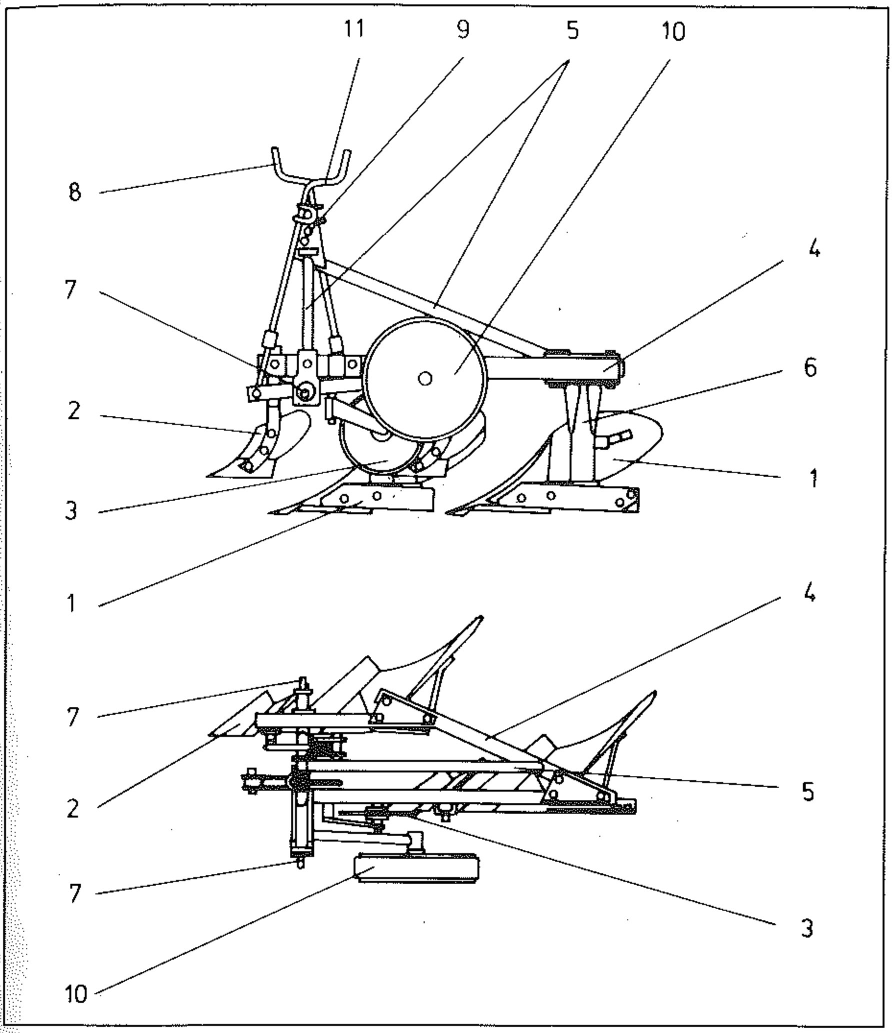

Fig. 18. Mouldboard plough (two-way, mounted) after Bernacki.
Soil engaging tools: 1. *Body,* 2. *Jointer,* 3. *Disc coulter,*
Supporting parts: 4. *Frame,* 5. *Headstock (column) with brace,* 6. *Shank,* 7. *Hitch bar with linking pivots,* 8. *Spindle to adjust width,* 9. *Hitchpoint for upper link,* 10. *Support wheel,* 11. *Spindle to adjust supportwheel.*

2.1.2 Functioning

The plough body cuts a slice of soil whose height and width are in the ratio of about 1:1.5 to 1:1. The share makes the horizontal cut while the edge of the share and mouldboard (shin) produces the vertical cut (often with the help of a coulter). The furrow slice is lifted, moved upwards along the mouldboard and turned over an angle of 120 - 150 degrees, depending upon the shape of the moulboard. When this operation is performed at a correct speed the soil is transported laterally over the width of the furrow (Fig. 19). The lifting, compacting, bending and turning processes will cause the slice to rupture both lengthwise and laterally. The free fall which follows these processes breaks up the soil even more. A tailpiece extends the funcion of the mouldboard and prevents the slice from falling back into the furrow.

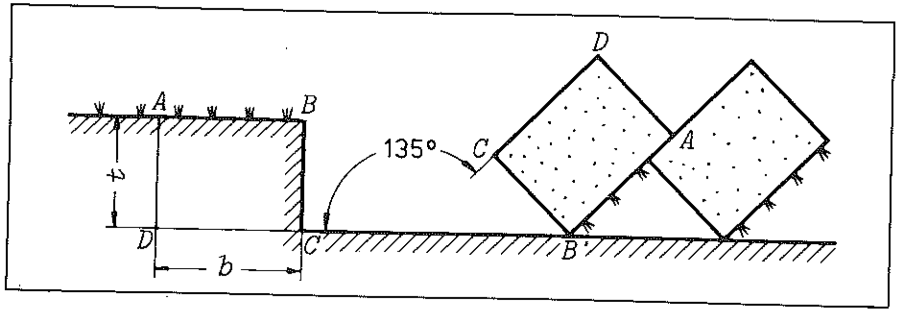

Fig. 19. Inversion and lateral transport of the soil slice during ploughing.

The degree of pulverization and loosening of the soil slice depends upon the shape of the plough body, the working speed, soil-type and the soil moisture content. The actual slice is not mixed. Material on the surface of the soil (plant residue, weeds, manure) is deposited in strips or "mats" on the bottom of the furrow and on the sides of the slice.
Attachments mounted in front of and on the mouldboard assist the functioning of the plough body. Knife, disc and mouldboard-mounted coulters cut the soil vertically in front of share or shin. The knife coulter has a sword-shaped cutting edge. The disc coulter is more expensive but less likely to become choked and requires less draught. Ripple-edged and notched (cut-out) coulters are particularly useful when the surface is covered with loose plant material.

The skim coulter (jointer, USA) is a small plough body. This attachment skims off the surface of the soil in front of the share over approximately half the working width. It moves the material from this strip into the main furrow.
The manure burying coulter (manure feeder, USA) is a steep curved and rounded plough body with a narrow cutting width designed to take the farmyard and green manure off from the side of the furrow, ensuring that this material is covered after the slice has been turned.
The extension on the mouldboard helps to turn the trash-covered surfaces and reduces the risk of choking. When large amounts of plant material have to be coped with, the clearance between two successive plough bodies and the height of the frame are vital factors for ensuring uninterrupted functioning.

Many types (standard and special-purpose) ploughs are available but only the main ones will be mentioned here:

Two-way ploughs are equipped with plough bodies which turn the furrow slices to one side only - usually to the right. This requires two specific methods: "face to face" and "back to back" ploughing. When a field is more than some 60 m wide it is advisable to arrange it in strips (lands) which are to be tilled separately. The "back furrows" (two furrow slices thrown back to back) and "dead furrows" (two open furrows together) will remain on the field after tillage.

One-way or reversible ploughs have two sets of bodies mounted symmetrically on a shared frame which can be rotated over 180 degrees (sometimes 90 degrees) along the longitudinal axis. This arrangement makes it possible to turn the furrows towards the same side of the field even though the plough travels in opposite directions. The bodies can be rotated or swivelled mechanically or hydraulically. If the plough is correctly adjusted, the surface of the soil is left almost level, which is important for irrigation and drainage purposes. The two-way and one-way ploughs are compared in Table 2.

Type	Advantages	Disadvantages
Two-way	1. Cheaper to buy, 2. Relatively simple to adjust, 3. Wear only on (replaceable) tools, 4. Large forces transferred via upper link (to activate hydr. control system), 5. More ploughs can work (offset) behind each other, 6. Simple way of mounting tools at the rear.	1. Dead- and back furrows unavoidable, 2. Careful layout of field necessary, 3. Width of individual lands no more than 60 m, 4. More attention is necessary during secondary tillage, 5. Large headlands necessary, 6. Plough does not easily penetrate in dry soils, 7. Contour-line ploughing on slopes is seldom possible.
One-way	1. Big savings in time on small fields, 2. Laying out of the fields in lands not necessary, 3. A level surface can be created, 4. Contour ploughing on slopes is possible.	1. More expensive as the two-way plough (2-3 times), 2. Heavy construction, causing a strong relief of the front axle load of the tractor, 3. Swivelling mechanism is subject to wear, 4. Symmetrical adjustment (of both sets of bodies) is difficult, 5. Weight limits the total number of bodies.

Table 2. Comparison between one- and two-way ploughs.

2.1.3 Linkage And Drive Systems

Drawn or trailer ploughs are fitted with wheels to control their depth. These ploughs are not linked to the tractor's hydraulic system - the only link is the hitchbar. They produce only a small additional load on the tractor's rear axle. Hitching and unhitching are quick and easy but they can be transported (to and from the field) only at low speeds. They may cause problems on small fields (e.g. in irrigated farming) because of the limited area for manoeuvring.
Semi-mounted ploughs are hitched at the front to the 3-point hitch system (or to the lower links) of the tractor. The plough is supported at the rear by a furrow wheel which is often hydraulically operated. This type of plough usually has 4 or more bodies. This mounting method prevents too much weight being taken from the tractor's front axle, as occurs in the case of heavy ploughs with a wide clearance between the bodies. The design of the semi-mounted plough allows more bodies than the mounted plough.
Mounted ploughs with up to 5 bodies are usually mounted to the tractor's 3-point hitch system. Quick-coupling systems can be fitted. Tractors with free-link operation of the hitch system can carry the plough during transport and support it by a gauge wheel when it is in operation. With automatic depth or draught control the plough is never supported by wheels. During operation a large part of the forces acting on the plough (including its own weight) are transferred to the rear axle of the tractor (less slippage). Care should be taken to ensure that the steering of the tractor is not over-affected by the considerable lessening of the load on its front axle.
The draught sensor for the automatic control system can be attached to the upper or the lower links. The control system does not guarantee a uniform depth but a more or less constant draught, i.e. a uniform pull load for the tractor. Strong power (about three times the weight of the plough) is needed to lift the plough from the soil and so the number of bodies is limited.
Large ploughs whose working width is wider than the tractor are sometimes mounted to the tractor in such a way that it does not have to travel with one wheel in the furrow. This system prevents the furrow bottom and the loosened soil from being compacted by the wide tyres. There must be no side draught on the tractor. The driver must be much more attentive when driving parallel to but clear of the furrow ("on land").
The latest development is a front-mounted plough combined with a rear-mounted unit. This combination makes maximal use of the drawbar power provided by very heavy tractors but which, until now, has been technically limited to a specific size of rear-mounted ploughs. A favourable distribution of the load is obtained, especially in the case of 4-wheel drive tractors. This development is not, however, within the means of small tropical farms.
Reversible ploughs require one or two extra hydraulic connections, depending upon the type of hydraulic cylinder used in the swivel mechanism. To achieve perfect operation the plough and tractor must be correctly matched.
The power requirement depends upon the specific soil resistance, the dimensions of the furrow, the shape of the mouldboard and the speed. One basic disadvantage of the plough is that the total power requirement has to be transferred to the soil through the driving wheels.
When operated at an average speed of 6 km/h and at an average depth of 25 cm, tractor ploughs require 15-22.5 kW (20-30 hp) per body on a medium heavy soil. The power requirement may rise to 30 kW per body under very heavy conditions.

2.1.4 Description Of The Implement And Tools

The mouldboard plough can be divided into two main sections (see Fig. 18):
- the soil engaging tools (plough body and extra attachments)
- the supporting parts (frog, frame, column for 3-point hitch, swivel system for one-way ploughs)

The soil engaging tools
The plough body (Fig. 20) consists of the share, mouldboard (with tailpiece), landside and frog.

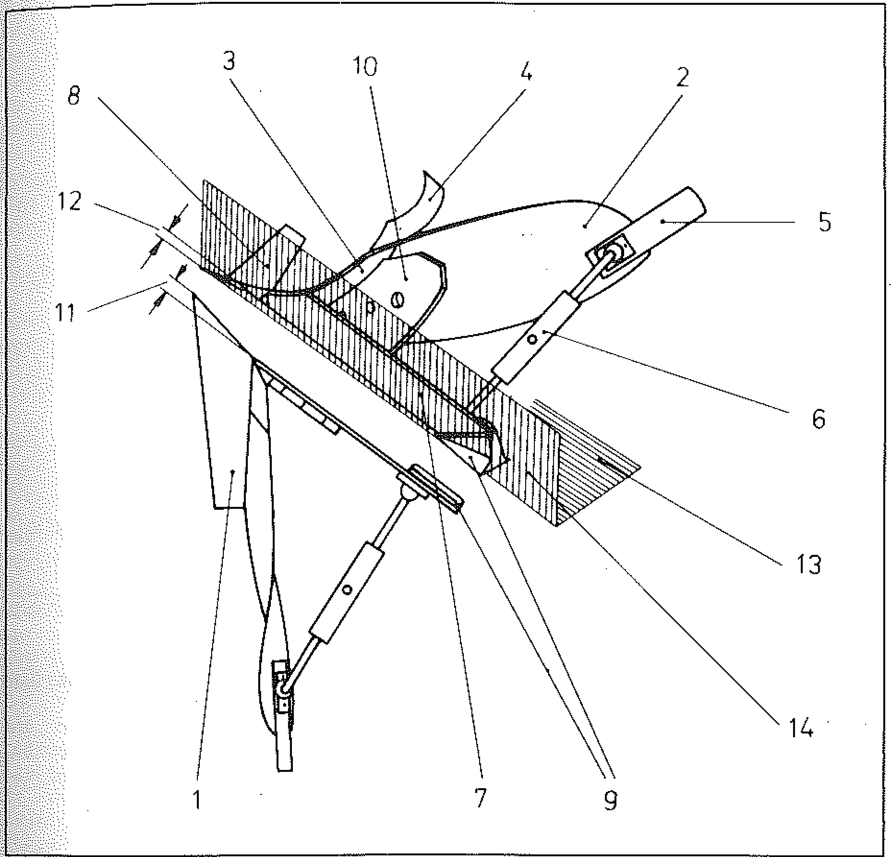

Fig. 20. Parts of a plough body:
1. Share,
2. Mouldboard,
3. Shin,
4. Trash board,
5. Tail piece,
6. Adjustable support stay,
7. Landside,
8. Mounted knife coulter,
9. Heel,
10. Frog,
11. Side suction,
12. Down suction,
13. Furrow sole,
14. Furrow wall.

The share:

The share is attached to the frog. It is subject to heavy loads and serious wear and tear and so it must be manufactured from soft-centre steel. This is a three-ply steel with outer layers of high carbon steel and a central layer of low carbon steel (0.5-0.9% carbon). Various shapes are available (Fig. 21):

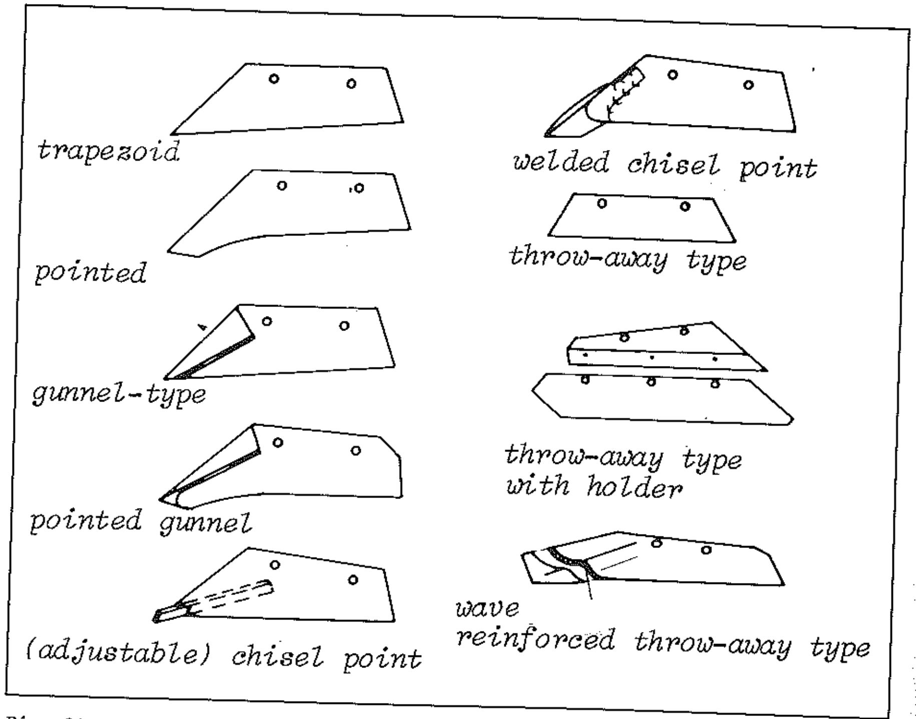

Fig. 21. Various share shapes.

a. trapezoidal. For light soils and straight cuts; The point is reinforced to allow resharpening and reforging.
b. pointed. For medium to heavy soils. This share is better than the trapezoidal shape for breaking up the soil, penetration, support, resistance to wear and susceptibility to damage from stones. It can be resharpened and reforged.
c. gunnel-type. The share point and cutting edge are supported by a vertical, V-shaped flange. This flange is also used to provide extra material for forging. This share is very rigid and resistant to wear and suitable for difficult conditions.
d. chisel point. For very heavy or stony soils, this share is similar to the pointed one except that, instead of the forgable point, it has a chisel which can be adjusted and used on both sides.
e. disposable (razor blade) type. This self-sharpening share is suitable for light to medium heavy stoneless soils. It can be used for a considerable period but is not forgeable because it is narrow and thin. Wear may destroy the downwards suction effect.

Only general instructions for adjusting the share can be given. A sideways (share point extenting approx. 10 mm into the furrow wall) and a downwards (share point approx. 10-15 mm deeper than the landside) suction effect should be created so that the share acquires stability and a good penetration capacity. Other important parameters (see Fig. 22) are the share point angle (the angle between the share edge and the direction of travel, usually 20-35 degrees) and the share lift angle (between the furrow bottom and share, perpendicular to the edge, usually 35-50 degrees).

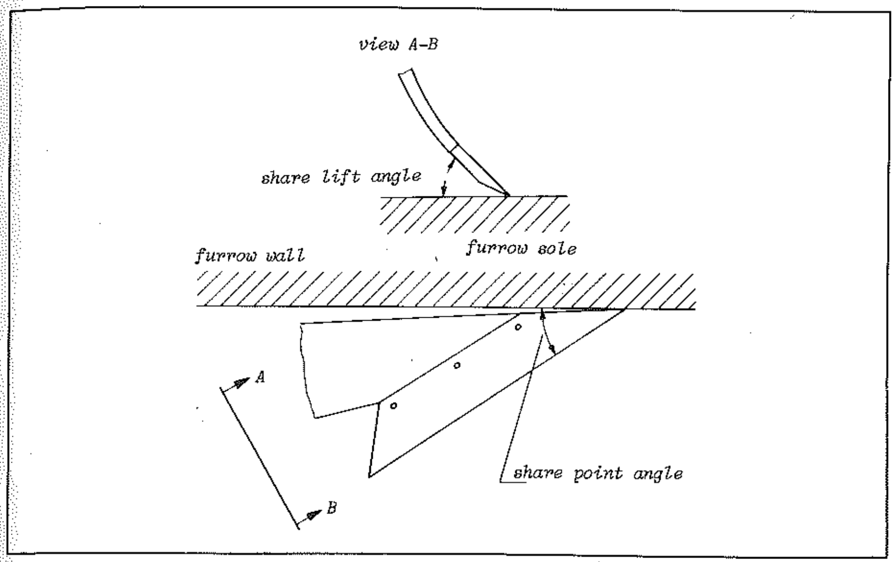

Fig. 22. Share angles of mouldboard ploughs.
bottom: top view, top: along cross section A-B (=rear view).

Wide angles are suitable for light soils or low speeds (animal draught) but narrow angles are more useful for heavy soils or high speeds. The different share shapes and angles should always be compatible with the shape of the mouldboard.

The mouldboard:

The mouldboard is mounted on the frog with countersunk bolts and often has a further link in the form of an angle strut. It should be stable, resistant to wear and elastic with, possibly, a small friction angle at the (soil/steel) surface. All these requirements are best fulfilled by three-layered steel. Both of the outer layers are very hard resistant steel while the central soft layer is made of low carbon steel and protects the outer layers against breakage.
The curvature of the mouldboard combined with the various positions of the share gives the following basic shapes of plough bodies (Fig. 23):
steep - for light, sandy soils, little inversion, low speed.
steep, short - for light, sticky soils, little inversion, low speed.
medium steep - for medium soils, average inversion, average speed.
inclined - for medium and heavy soils, average to pronounced inversion, average to high speeds.

helical - for heavy slaked soils, almost complete inversion, average to high speeds.
universal - for all soil types (exept extremes), average inversion, average speed.
spiral - for the heaviest soils, complete turning of the sod, high speed - also suitable for sloping soils.
slatted - for very sticky soils.

Another system divides plough bodies into:
Continental body (cylindrical): for light to average soils.
General purpose body (semi-helical): for nearly every soil type.
Semi-digger body (helical, extended): for heavy soils and on slopes.
Grassland body (helical, flat, extended); for clearing grassland.

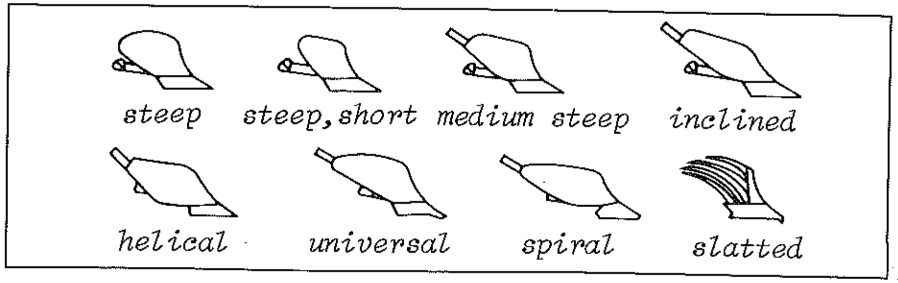

Fig. 23. Various mouldboard shapes.

The choice of plough bodies depends on the soil type, topography, the required inversion and the speed. Working widths of up to 42 cm and working depths of up to 35 cm per plough body can be achieved (excluding special "deep digger" ploughs). Plough bodies with a replaceable shin (the part suffering most wear) are widely used at present.

The tailpiece:
The tailpiece is used to improve the inversion and crumbling of the soil. It is mounted on the upper section of the mouldboard and can be adjusted to the ploughing depth.

The landside:
The landside is mounted on the frog and supports the horizontal forces exerted by the wall of the furrow and the vertical forces from the furrow bottom, especially when the tractor hydraulic system is in free-floating mode. The rear part is replaceable after it is worn out. The landside is sometimes spring-mounted on ploughs designed for tractors with automatic hydraulic control. A roller is better than a rigid landside on slopes and for skim ploughing. This roller is a rear furrow- wheel mounted at an angle of approx. 45 degrees to the furrow wall. Some makes allow a coulter to be mounted on the front part of the landside; this is cheaper than a knife-coulter and prevents choking.

The frog:
The frog must be strong resistant to bending and torsion. The share, mouldboard and landside are attached to the frog. The parts of the plough which enter the soil convey the draught forces to the frame through the frog.

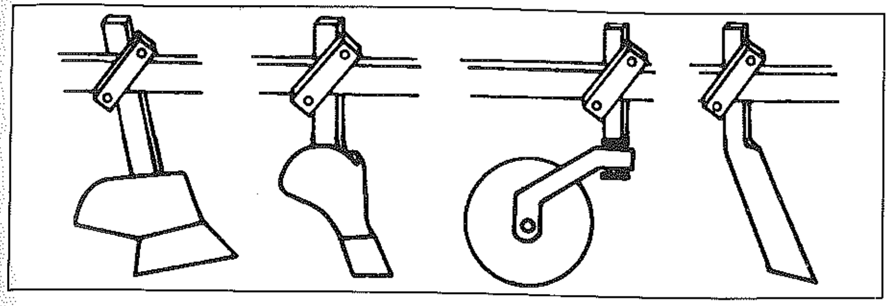

Fig. 24. Front-mounted tools.
From left to right: jointer, manure feeder, disc coulter, knife coulter.

Front- or body-mounted tools:
Front-mounted tools are fitted in front of the plough body on the shank or frame and are adjustable. These tools improve the quality of the tillage (see Fig. 24), as do the body-mounted tools (see Fig. 25).

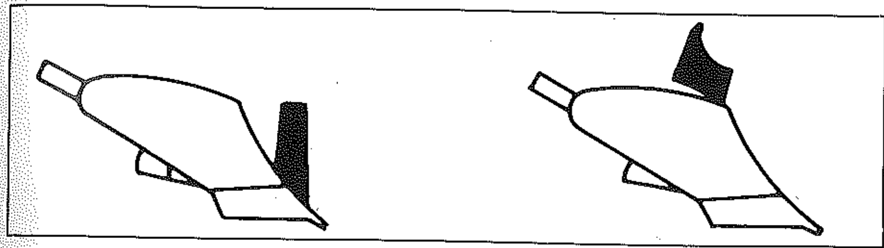

Fig. 25. Body-mounted tools. left: coulter, right: trash board.

Knives, discs or mounted coulters separate the furrow slice vertically from the undisturbed soil. The skim coulter, manure-burying coulter and trash board are used to cleanly bury plant residue or manure.

Supporting parts
The supporting parts of a plough are the frame and shanks. The shanks are either fixed rigidly to the frame or protected against overload (rocks, roots). The technical solutions used to provide protection against overload range from shearbolts to fully automatic mechanic, hydraulic or pneumatic systems. These "stump-jump" systems effectively prevent the plough body or shank from breaking and permit uninterrupted operation. As shown in Fig. 26, the plough body moves away from the obstacle and automatically returns to its original position.

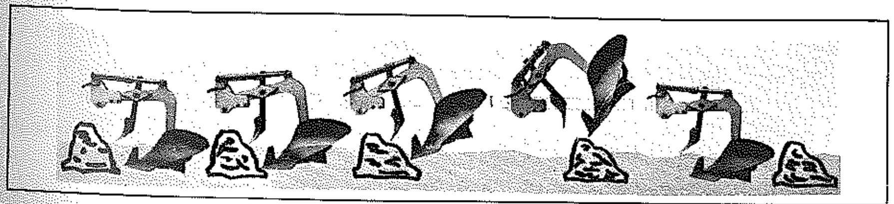

Fig. 26. Safety devices (protection against rocks and stumps) on a mouldboard plough.

A flat-frame design using spring steel with lengthwise and crossways bars makes the entire plough suitably elastic. A beam design with profiled steel (hollow bars are most commonly used at present) allows the number of plough bodies to be changed more easily (modular design principle). Depending upon the type, the frame is supported by the plough head or by wheels (partly or entirely; mounted, semi-mounted or trailer plough). The frame height and the clearance between the bodies should be large enough to avoid choking when plant residue is being ploughed under. The trailer plough can be transported by using a lifting device.

The ploughhead:
The ploughhead of mounted ploughs consists of the column. Its dimensions (coupling pins for lower and upper links) have a definite influence on the plough's behaviour. DIN and ISO standards are applied. The swivel system (semi- or fully automatic) is also part of the head on reversible ploughs.

2.1.5 Adjustment, Operation

The plough frame should be completely level during ploughing to ensure that all the plough bodies work at the same depth. A 3-point hitch system is adjusted by changing the upper link and one of the lift arms for the lower links.

2.1.5.1 **Working Depth** - The depth for trailer ploughs is adjusted by the depth wheels; for semi-mounted ploughs, by the lower links and depth wheel (draught control). In the case of mounted ploughs, adjustments are made either to the upper link (free-floating action) or the hydraulic system. The lateral levelling is controlled by the tractor's lift arms for two-way ploughs and, for mounted reversible ploughs, by a spindle on the plough column (headstock).

2.1.5.2 **Working Width** - The plough's working width is determined principally by the number of bodies and the cutting width of each body. On many new ploughs (both one- and two-way models) the location of the bodies in relation to the tractor can be changed. The total working width on some ploughs can be varied by adding or removing plough bodies.

2.1.5.3 **Tillage Intensity** - The tillage intensity depends upon the speed, the shape of the plough body and the working depth. The intensity can be increased by using front-mounted or rear-mounted (crumbling, packing) tools.

2.1.5.4 **Adjusting Front-Mounted Tools** -
Knife coulter: 0-30 mm in front of, 10-30 mm beside of and approx. 25 mm above the point of the share.
Disc coulter: as deep as possible (axis 50 mm above the soil surface), approx. 10-20 mm beside the share point (towards the unploughed land).
Skim coulter: small angle of attack, 40-80 mm deep, 10-20 mm beside and approx. 250 mm in front of the point of the share. The width is generally 0.3-0.7 times the width of the plough body and the depth is 0.3-0.5 times the depth of the plough body.

2.1.5.5 **Handling** - Ploughs can be mounted and dismounted by one man but not easily. Adjustment requires some technical knowledge. Ploughing in particular requires a high standard of skill and knowledge on the part of the driver. Frequent re-adjustments of the plough are needed if the soil conditions are irregular.

2.1.6 Technical Data

Working width per body	up to 42 cm
Working depth	up to 35 cm (more for special ploughs)
Number of bodies	up to 12 (up to 24 in case of reversible ploughs)
Frame height	up to 90 cm
Clearance between bodies	up to 110 cm
Weight	up to 310 kg per body
Overload devices	protection against rocks by means of shearbolts, helical springs, hydraulic and pneumatic cylinders, overload protection on mountings.
Power requirements	15-25 kW per body (20-35 hp/body)

2.1.7 Literature

See literature of chapters 1 and 2.0.

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Traulsen, H. and W. Holtz, 1982. Streifenpfluege in der Praxis. Landtechnik, 37(6): 288-290.

Zumbach, W., 1980. Tests comparatifs de charrues portees. Technique Agricole, 42(11): 518-528.

2.2 The Disc Plough

2.2.1 Use And Assessment

The disc plough (Fig. 27) is used mainly in tropical and subtropical regions for the following jobs:
- land clearance,
- primary tillage,
- ploughing land containing stones and roots,
- seedbed preparation,
- deep tillage between rows of trees,
- working in large amounts of plant residue,
- ploughing in regions with a high risk of erosion,
- ploughing on sticky waxy soils and soils which tend to form plough soles.

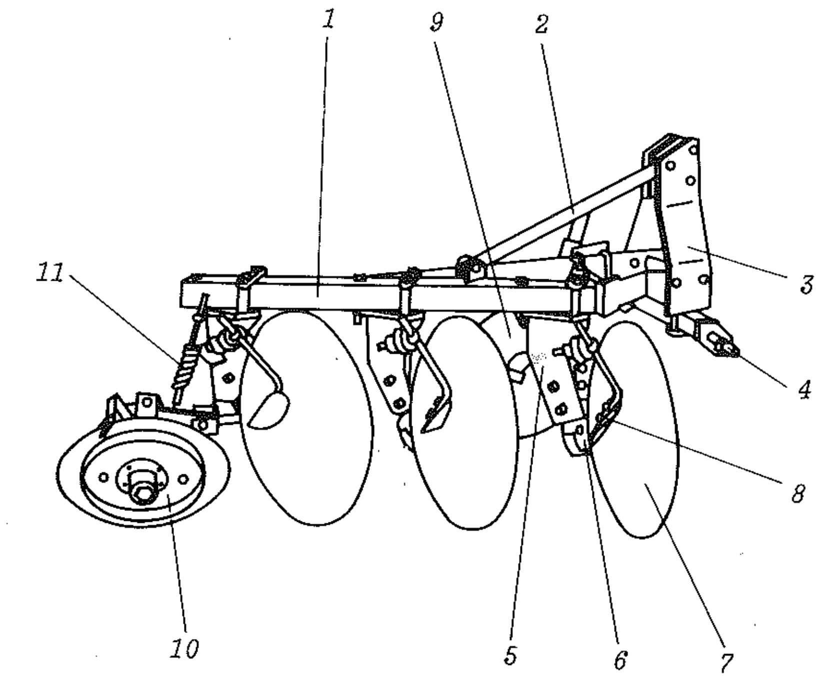


Fig. 27. Disc plough:
1. Frame,
2. Brace,
3. Headstock,
4. Hitch bar,
5. Shank,
6. Bearing,
7. Disc,
8. Scraper,
9. Support (land) wheel,
10. Furrow wheel with collar,
11. Spring.

There is little difference between mouldboard and disc ploughs as regards (Fig. 28):
- effect,
- maintenance,
- reliability,
- power requirements,
- total tillage costs.

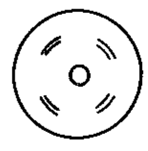
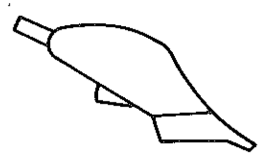
implement type / *criteria*		
inverting	*medium*	*good*
mixing	*medium*	*hardly*
crumbling	*medium/good*	*medium*
burying of long stubble	*not completely*	*completely*
plough sole compaction	*little*	*by landside (heel) less by share*
susceptibility for damage by roots and stones	*little*	*more*
possible fields of use	*heavy, dry, stony soils forest soils*	*clean fields*
durability	*high*	*medium*
weight	*high*	*lower*
draught requirement	*high*	*high*

Fig. 28. Differences between mouldboard and disc ploughs after Wieneke.

Penetration by disc ploughs presents problems on dry heavy soils. Penetration can be achieved only with a suitable high load (up to 500 kg per disc by adding weights). Unlike mouldboard ploughs which have to be protected by special mechanisms and suitable shares, however, disc ploughs roll over roots and stones, thus preventing damage. A constant working depth is very hard to maintain. It is also difficult to keep to a straight line of travel. Generally speaking, the soil is tilled less intensively and with less inversion than with a mouldboard plough.
Sticky soils cause fewer problems. The discs rarely have to be sharpened or replaced since their rotation produces a long cutting edge.

The disc plough's advantages over the mouldboard plough are:
- only partial inversion of the soil so that plant residue is left on the surface, thus reducing the erosion risk and water losses by evaporation,
- mixing action on loose soils,
- rolls over obstacles so that hardly any breakage occurs,
- lower risk of choking (sugarcane, cotton, maize),
- fewer problems with sticky soils,
- hardly any smearing of the furrow bottom (plough sole),
- the wear is spread over the entire circumference of the disc (2 m of cutting edge on discs with a diameter of 65 cm),
- the discs are self-sharpening,
- easier adjustment.

The disadvantages of the disc plough are:
- penetration is difficult in hard soils,
- heavy weight (and consequently, high prices),
- greater lifting capacity required from the tractor's hydraulic system,
- furrow wheel is needed for controlling for depth and lateral movement,
- not usually suitable for slopes owing to the strong lateral forces,
- the plough's weight may cause compaction of the furrow bottom,
- less efficient weed control,
- soil surface is not so level after ploughing (irrigated fields).

2.2.2 Functioning

Unlike the mouldboard plough, a disc plough will not penetrate into the soil of its own accord but needs a heavy load. The soil is not carried over the surface of the disc (as with a passive share) and so there is less scouring. The disc is rotated by the soil reaction; it lifts and deposits the soil not with a winding but with a pouring tumbling movement. When combined with the differences in the acceleration forces exerted on the soil while it is on the disc - those forces increase from the centre towards the edge -, this movement causes the disintegration, mixing and loosening of an aggregated soil. In the case of cohesive soils this movement may produce deposits of clods along a lâteral axis, thus forming the unwelcome "rabbit holes". The furrow slices which form in these soils are difficult to crumble by secondary tillage operations. Consequently, the standard of the tillage depends to a large extent upon the type and condition of the soil. Like the mouldboard plough, the disc plough leaves an open furrow.
There is less likelihood of forming a plough sole with a disc plough because:
a. The disc plough tears rather than cuts and so no cutting surface can develop (the tillage horizon is corrugated);
b. There are no landsides and heels which, on the mouldboard plough produce further smearing and compaction.

In the case of compactible soils, however, the total weight of the heavy plough may cause compaction over a thicker layer (5 - 10 cm) below the furrow bottom.
Large discs require less draught and cut through plant residue more satisfactorily.

2.2.3 Linkage And Drive System

Disc ploughs are designed in the form of trailer, semi-mounted and mounted ploughs. Heavier larger units can be lifted hydraulically on support wheels. The discs are driven by the soil resistance and movement. Owing to its heavy weight the draught required (per volume unit of soil moved) for a disc plough is more or less the same as for a mouldboard plough despite the rolling action. For successful operation the hitch point for trailer ploughs should be as low as possible on the tractor; in the case of mounted ploughs the upper link should be only slightly inclined forward.
When more concave discs are used to obtain better crumbling the draught requirement will increase with the degree of curvature.
This requirement does, of course, depend to a large extent upon the soil conditions and is generally 15-20 kW per plough body. At 5.5 km/h a capacity of 0.4 ha/h can be expected for each metre of working width.

2.2.4 Description Of Implement And Tools

Disc ploughs (see Fig. 27) are very heavy implements equipped with between one and eight concave discs. The working depth is 25-40 cm. Each disc is mounted on its own shank with a bearing (frog). The shanks are mounted on a sturdy steel frame diagonally to the direction of travel. The disc angle and tilt angle (Fig. 29) are adjusted on the frog bearing and can be adapted to the field conditions. The diameter of the discs ranges from 560 to 810 mm. The discs' concavity - defined as the deepth of the centre in relation to the edge - is between 60 and 120 mm.

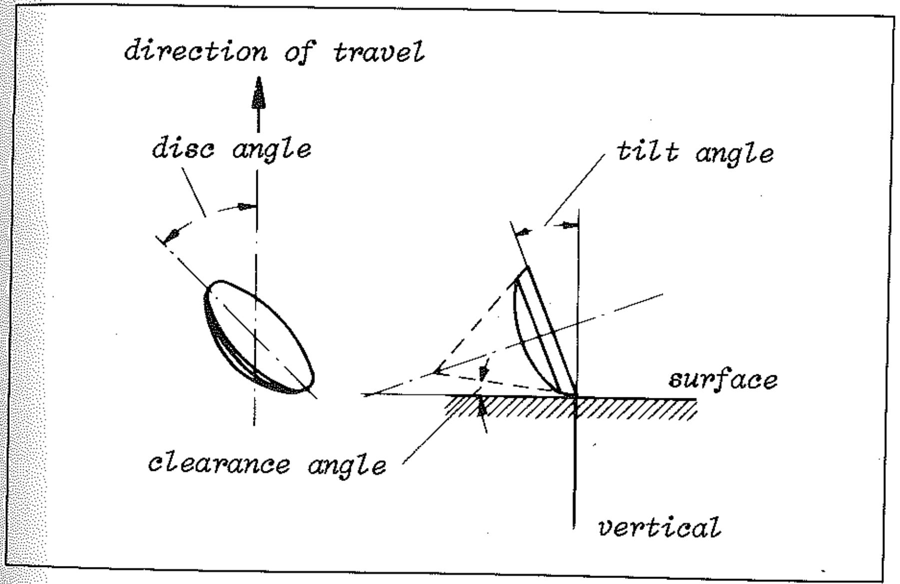


Fig. 29. Angle definitions on disc ploughs
left: top view, right: side view.

A neat solution was found for one-way or reversible disc ploughs to avoid the need for a double set of soil-engaging tools, as is the case with reversible mouldboard ploughs. The discs are mounted on a sub-frame, usually one heavy beam, which is attached to the main frame by a pivot near its centre and can be rotated through an angle of 30-40 degrees. To keep the same disc angle for both ploughing directions a lever system is employed to rotate the shanks of the individual discs through a small angle when the sub-frame is rotated. At the same time a second system of levers reverses the rear furrow wheel (see Fig. 30). This rotation from left-hand to right-hand plough and vice versa can be performed manually or hydraulically. The main (or sub-)frame should have a clearance of at least a few centimetres from the discs.

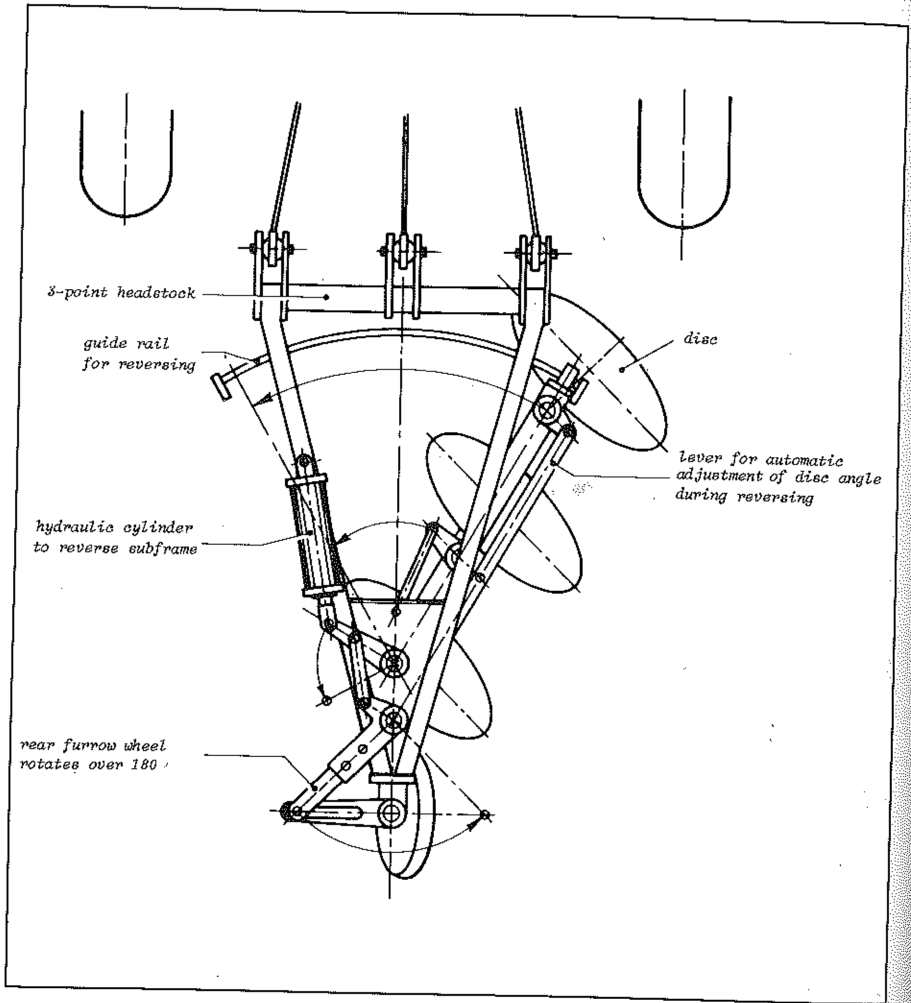


Fig. 30. Three-furrow reversible disc plough.

An opening in the center of the discs is used to mount a tapered roller bearing which can be adjusted by a castle nut to prevent to much play. The dimensions (diameter, thickness) of the discs are usually given in inches and are inter-related on the basis of a specific ratio.

disc diameter	thickness disc	depth of work	use
660 mm (26 in)	5.0-6.5 mm	10-30 cm	skim ploughing
710 mm (28 in)	6.5-7.5 mm	10-35 cm	skim- and deep ploughing
810 mm (32 in)	8.0 mm	10-45 cm	deep ploughing

The discs are made of specially treated manganese silicium steel which is very resistant to wear. The hardness is comparable to that of plough shares and may be as much as 600 HV (Vickers Hardness).
Triple-layer types of steel do not have any advantages in this respect because, after the circumference of the disc has been worn down, the various layers will be exposed and may break. The direction of the disc rotation is always in the direction of travel since they are driven by the slice of soil moving along the concave inner side of the disc. Scrapers shaped like hoes or small mouldboards (Fig. 31) remove the soil from the disc and improve the inversion. Mounted ploughs are usually equipped with a rear furrow wheel.

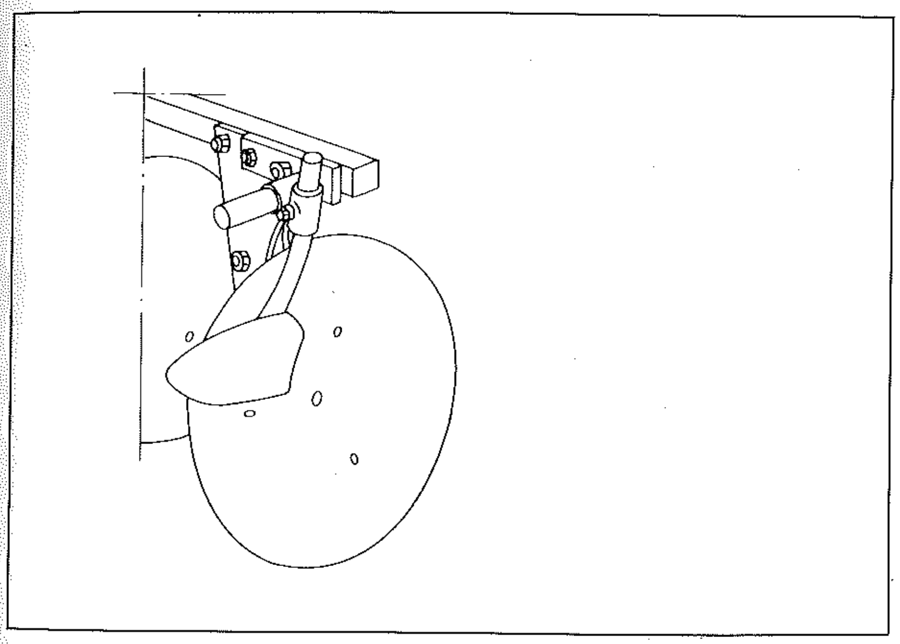


Fig. 31. Disc with scraper.

Every trailer disc plough has a land wheel attached to the rear lifting mechanism and a front and rear furrow wheel. The rear furrow wheel and the rear gauge wheel with their adjustment mechanisms form the rear bridge. The furrow wheels are angled at anything up to 45 degrees from the surface and are equipped with a collar. These wheels absorb at least part of the lateral forces exerted by the soil. With this wheel arrangement, however, a trailer plough will always tip over when making a right-hand turn. So the plough should always be turned to the left.

2.2.5 Adjustments, Operation

2.2.5.1 Working Depth - The working depth is maintained mainly by the weight of the plough. The disc and tilt angle which must be adapted to the soil conditions also strongly influence the depth control (see Fig. 29). The following settings may be used:

soil	tilt angle (vertical)	disc angle (in deg) (horizontal)
hard	3-20	45-50
cohesive	10-25	43-48
loose	15-30	40-45

The disc angle can be adjusted (often in gradations) on every plough, as can the tilt angle on many of them. When the disc is tilted, an angle of clearance should be allowed to prevent constraint upon the disc's tearing action and possible smearing of moist soil (see Fig. 29). The wider the tilt angle, the less freedom is left for the disc angle because, otherwise, the back of the disc may scour against the furrow wall (more power required and more wear caused).

2.2.5.2 Working Width - There are only limited possibilities of changing the working width. It can be adjusted by:

- Changing the angle between main cross-bar and rear bridge and the angle between main cross-bar and front bridge or 3-point hitch headstock,
- Adjusting the gauge wheels,
- Adjusting the disc-mounting clamps on the frame.

The cutting width of each disc can be changed by altering the disc angle. On reversible ploughs this can be achieved by adjusting the degree of the subframe rotation. Horizontal lateral forces must be absorbed by the slanting furrow wheels. For trailer ploughs these forces should also be absorbed by the gauge wheels running on the undisturbed soil; as little as possible should be absorbed by the tractor (to avoid side draught). Collars on the furrow wheels improve the guidance of the plough. With the elimination of the horizontal forces the friction between the discs and the furrow wall is also reduced, causing less wear. Moreover, the theoretical centre of gravity is shifted towards the furrow, eliminating the need for counter-steering. Adjustment of the axle and spring tension can often

produce the penetrative forces of the furrow wheels which are required for guiding the plough. The crossbar with mounting pivots can be shifted laterally and rotated (mounting pivots are off-centre) in order to align the disc plough behind the tractor.

Correct setting of the tractor's front and rear track widths is most important for guiding the plough and for determining the cutting width of the front discs. This is particularly important in the case of reversible ploughs.

2.2.6 Technical Data

Number of discs	2 - 8
Diameter of discs	560 - 810 mm
Working width	50 - 200 cm
Working depth	20 - 40 cm
Frame height	65 - 80 cm
Clearance between discs	50 - 75 cm (partly variable)
Weight per disc	150 - 250 kg
Power requirement per disc	15 - 20 kW (20-30 hp)

2.2.7 Literature

See literature of chapters 1 and 2.0.

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Harrison, H.P., 1977. Soil reacting forces for disks from field measurements. Transactions of the ASAE, 20(5): 836-838.

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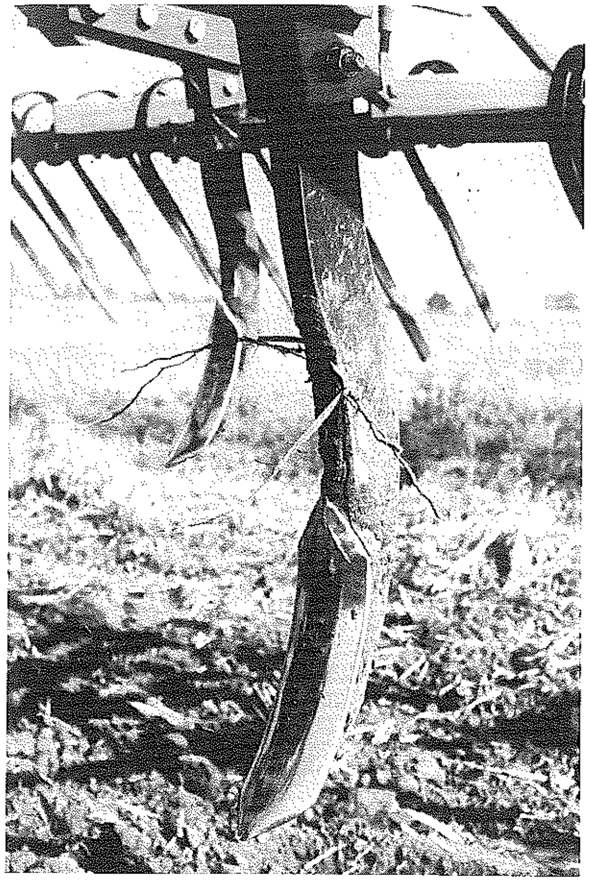
2.3 The Chisel Plough and Cultivator



2.3.1 Use And Assessment

The chisel plough and cultivator are generally used for the following purposes:

- stubble tillage,
- working in straw and harvest residue,
- mechanical weed control (especially root-propagating weeds),
- deep tillage (alternative to ploughing),
- loosening hard dry soil before ploughing,
- breaking up hard layers below the normal ploughing depth (hardpans, plough soles),
- ploughing-in manure.

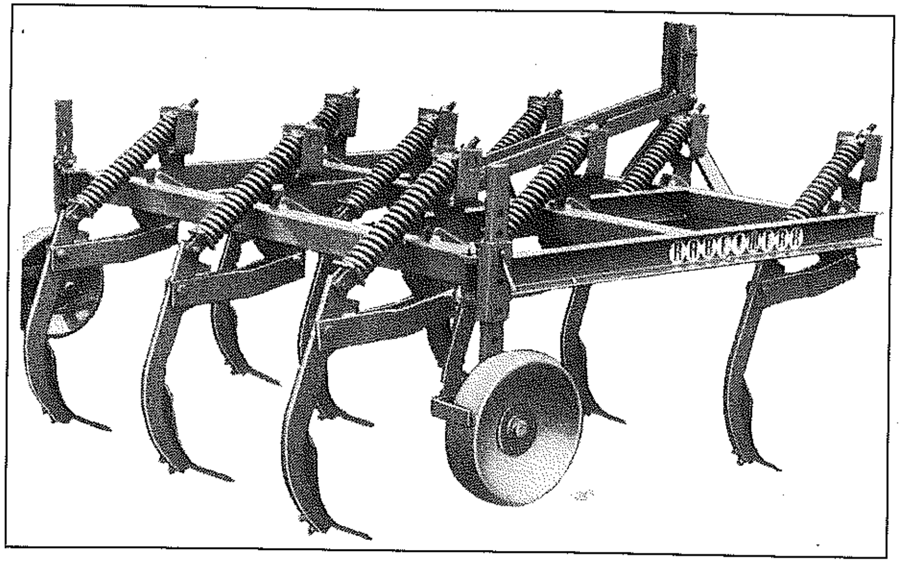


Fig. 32. Chisel plough with three cross bars and rock protection device per tine.

It may be appropriate at this point to explain the names used to head this chapter. The term "chisel plough" is generally used for a heavier type of implement designed for heavy duty, i.e. primary tillage. Essentially, this implement is equipped with rigid shanks. The term "cultivator" is applied mainly to lighter implements and, in the USA, often to crop maintenance implements. They may be equipped with both rigid and spring tines or shanks.

Chisel ploughs or cultivators (Fig. 32) are suitable for primary tillage in the tropics and subtropics because of their non-inverting action: the soil is sufficiently loosened and mixed without too much crumbling. In addition, after stubble tillage and the ploughing-in of straw the soil surface still retains a high percentage of plant material to control wind and water erosion. Tillage operations should not be carried out when the soil is too wet. Fig. 33 and Table 3 give some criteria for choosing and using the chisel plough. Special mention should be made of the combination of chisel plough and rear-mounted tools (Chapter 8).

Chisel ploughs have the following advantages:

- wide range of possible uses (stubble tillage, mulching, primary tillage for seedbed preparation, deep loosening, breaking up plough soles);
- they may replace disc or mouldboard ploughs under certain conditions;
- suitable for use in the tropics; they loosen soil without inversion so that organic material decomposes more slowly; moist soil is not transported upwards; the soil surface retains an adequate cover of plant material (wind and water erosion);
- they can be used on extremely heavy soils where the quality and capacity of other types of ploughing are unsatisfactory;
- a high capacity with brief preparation time, making their operation very efficient;
- substantially less time required than for mouldboard ploughs;
- the power requirement per tilled cross-section is less than for the mouldboard and disc ploughs;
- the tractor needs only a comparatively small lifting power; they can be combined with rear attachments and sowing equipment;
- effective against root-propagating weeds;
- highly reliable.

Their disadvantages are:

- they require high speeds (8-10 km/h) when harvest residue is to be worked in; so greater demands are made on the driver and tractor, especially when working across crop rows;
- very often primary tillage needs to be repeated (usually at increased depth and, if possible, crosswise);
- the working width and speed must exceed minimum values if a good performance is to be achieved and so large tractors are required (at least 45 kW); this is possible for small farms only on a cooperative basis;
- the chisel plough can replace the inverting plough only to a small extent and so both implements are needed;
- the mixing action is often inadequate for working in straw on light soils.

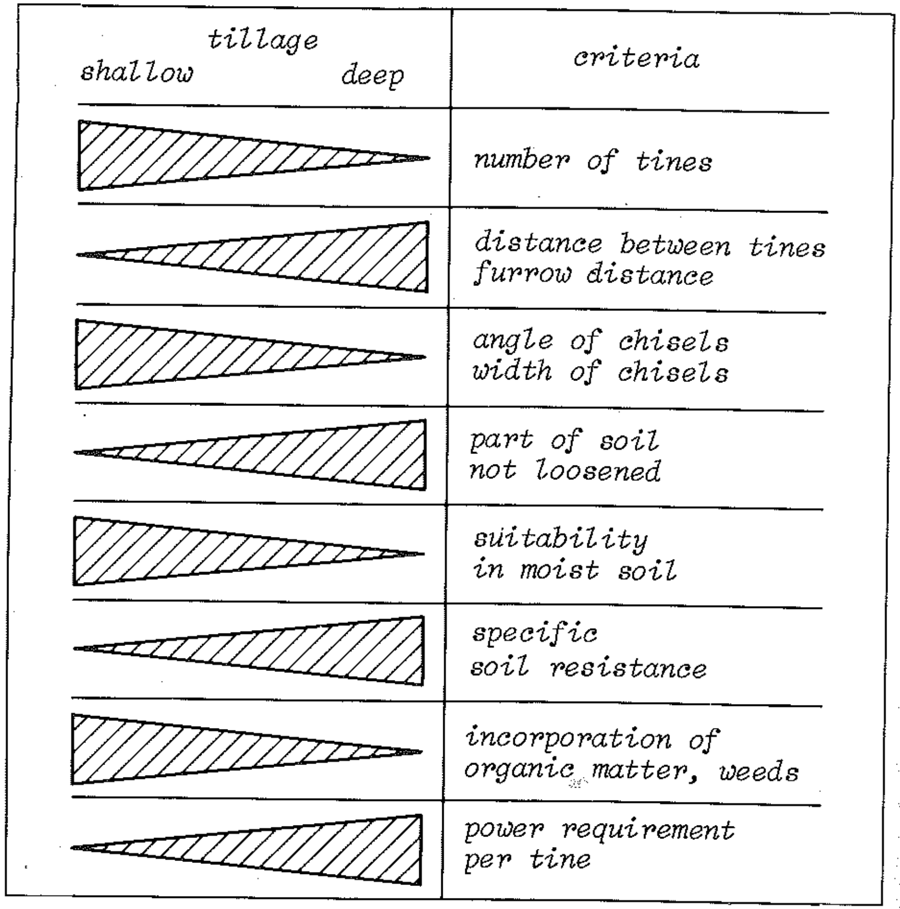


Fig. 33. Criteria for the choice and assessment of a chisel plough.

2.3.2 Functioning

Chisel tines cut vertically through the soil. The soil moves upwards along the curve of the chisel and is broken up by the flexing forces. The lateral shattering effect (becoming more pronounced towards the surface) results in complete loosening of the soil down to a specific depth. The cross-section of the soil tilled by a chisel tine can be represented as a triangle (Fig. 34). Consequently, the bottom of the tilled layer left by the chisel plough is shaped like a washboard. When wide duckfeet chisels are used, the ridges left between the chisels are obviously smaller.

Very satisfactory mixing and loosening is ensured in relatively dry soil;

the soil is broken up perpendicularly to the direction of travel at an angle of approx. 50 degrees from the surface. As the soil moisture content increases, this angle becomes wider and the tilled area smaller. In very moist soils it may be as much as 90 degrees in which case the tine cuts only a very narrow groove in the soil and brings up "sausages" of smeared soil. These harden very quickly as they dry in the air and are very difficult to crumble by means of later tillage operations. These narrow furrows may also be cut in drier soils when the operating speed is too low, i.e. less then 6 km/h.

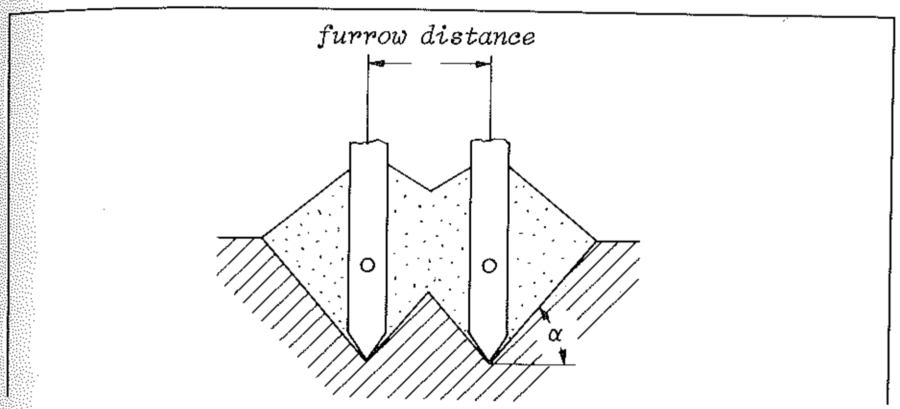


Fig. 34. Cross section of the soil actually loosened; two tines, relatively dry soil.

The advantages of spring tines over rigid tines are the possibility of diverting around obstacles, the better self-cleaning action and, under some conditions, the more effective crumbling of hard clods. The main disadvantage is that during the diversionary movement the tine moves not only backwards and sideways but also upwards: the angle of attack and working depth are changed and the lateral dispersal is decreased, leaving unworked strips. Spring tines raise more "sausages" when the soil is too wet. The spring tine is less suitable for deep tillage. Spring-loaded tines have proved a valuable compromise between rigid and spring tines.
The standard chisel plough may be equipped with various sizes of single or dual-pointed shovels or chisels. Dual-pointed chisels can be used on both sides. A twisted chisel turns the soil more efficiently. Alternate right- and left-hand chisels are used to eliminate the lateral forces.

Various sizes of reversible ("diamond point", see Fig. 41) or duckfoot chisels are often used for shallow tillage (stubble tillage and weed control). In order to cut every root duckfoot chisels should be mounted so closely together that their cutting widths overlap. Chisels are mounted in rows one behind the other, applying a staggered configuration to ensure free flow. Some interval between the tines, furrows and crossbars (Fig. 35) and the frame clearance are essential for effective use and for uninterrupted working.

The cutting widths of pointed chisels do not overlap but all the soil near the surface is nonetheless loosened owing to the triangular shape of the dispersed soil mass. As the lift angle of the tine (angle of attack) is increased, less soil will be pushed upwards. The angle of the cultivator chisels should be sufficient (up to 60 degrees) to bring weeds (especially root-propagating weeds) to the surface and to plough-in straw and weed seeds. If it is to be satisfactorily ploughed-in, the stubble should be short (< 10 cm) and straw should be spread evenly. The shorter the chopped straw, the deeper it will be ploughed-in. A good part of the material will, however, always remain on the surface.

When chisel ploughs are used on slopes (following the contour lines) the effect of the side draught must be taken into account. In particular, trailer implements may no longer follow the tractor in a straight line but at a slight angle. This may cause fluctuations in the intervals between furrows, depending upon the arrangement of the tines.

	cultivator	chisel plough	subsoiler
intended use	shallow stubble tillage	loosening at ploughing depth	loosening and breaking up of plough sole
chisel type	wide to normal	normal to narrow	narrow to normal
tine type	spring, spring loaded or rigid	spring loaded or rigid	rigid
angle of attack	up to 60 deg.	30 deg.	30 deg.
distance between tines	at least 55-60 cm	at least 70 cm	at least 75 cm
furrow distance	about 20 cm	25-30 cm	30-50 cm
required frame height	70 cm	70-80 cm	70-90 cm
rear mounted tools	necessary	desirable	desirable
working depth	5-15 cm	15-30 cm	30-50 cm

Table 3. Criteria for the choice of a chisel plough/cultivator/subsoiler.

When used for "stubble mulch tillage" in dryland farming systems chisel ploughs should have disc gangs in front. The discs can cut through (large amounts of) thrash, preventing the plough from becoming choked. Pointed or twisted chisel ploughs can be used for primary tillage while sweeps are usually fitted for fallowing operations or secondary tillage.

It must be emphasized that, basically, the distance between the tines, the frame clearance and the speed have more influence on the quality of the work than the implement shape and adjustment.

Table 4 shows the crumbling effect of a special type of chisel plough (Fig. 36) in heavy, hard and dry soils compared with the crumbling effect of a mouldboard plough.

Primary tillage using a chisel plough should generally be repeated, posssibly crosswise with extra depth. On sloping land, however, operations along the slope should be avoided, if possible, because of the risk of erosion. The efficiency of chisel ploughs is considerably improved by rear-mounted tools for loosening, crumbling, levelling, mixing, packing, etc. In many cases the chisel plough's working depth is controlled by these attachments (see Chapter 8.1, Fig. 127).

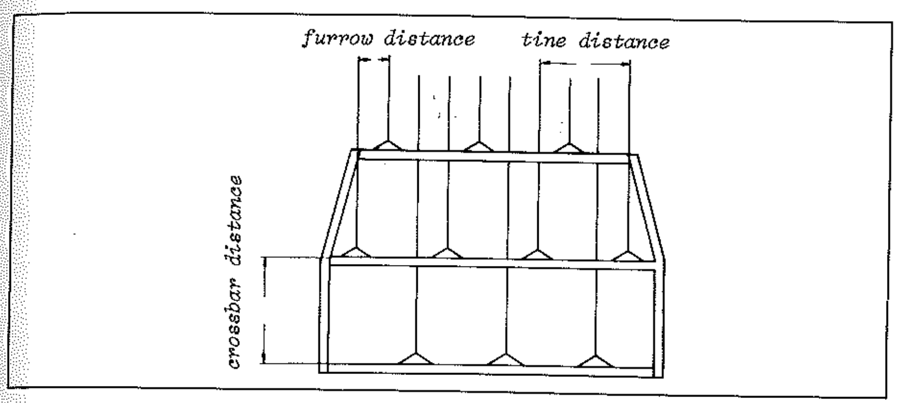


Fig. 35. Frame of a chisel plough with three crossbars, indicating distances between tines, furrows and cross bars.

implement	speed	percentage (weight) of size class > 80 mm	40-80 mm	20-40 mm	2-20 mm	< 2 mm
	km/h	%	%	%	%	%
chisel plough VICON Jumbo buster	6.7	18.1	19.2	19.3	34.7	8.7
mouldboard plough (control)	6.1	48.4	17.6	12.2	18.3	3.5

Table 4. Distribution (by weight) of the various size fractions.

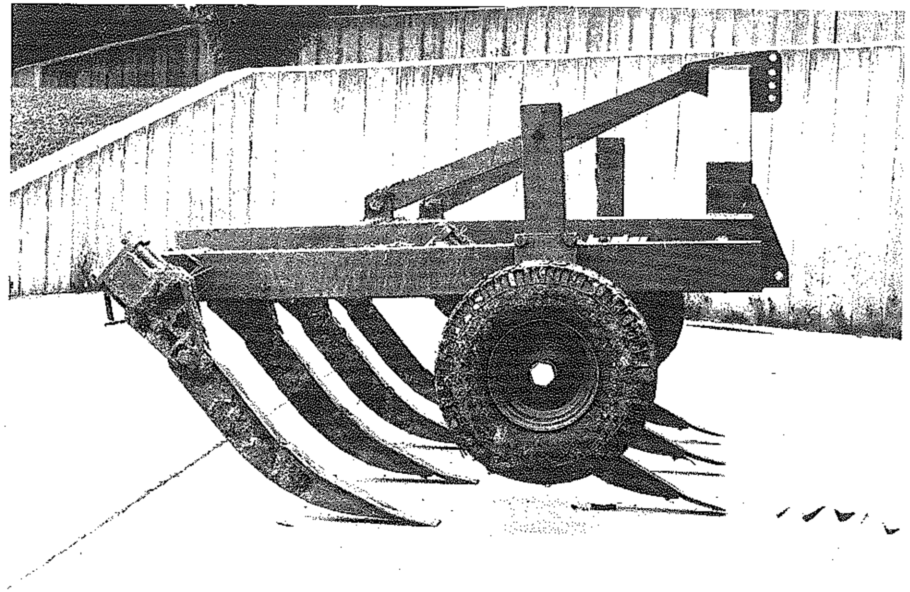


Fig. 36. Chisel plough with tines at a small angle of attack.

2.3.3 Linkage And Drive System

Chisel ploughs with a working width of up to 6.5 m are usually equipped for the 3-point hitch system, often with quick-coupling devices. The larger implements (with working widths of up to 20 m) are semi-mounted or trailed.

The comparatively light weight of the mounted chisel plough and its short length (centre of gravity is close to the tractor) mean that the tractor's hydraulic system needs only a comparatively low lifting capacity. So the mounted chisel plough offers favourable possibilities for combinations of implements.
Larger chisel ploughs require one or two extra hydraulic outlets on the tractor so that they can be lifted and folded to transport width.

The power required by a chisel plough depends upon the number of tines, the distance between them, the working depth, speed, type of chisel, type of tines (rigid, spring-loaded, springs), the tines' lift angle, the soil condition and type.

Some basic factors are given in Fig. 37. In theory, vertical tine A requires the most draught traction. Moreover, it is difficult to pull a tine of this shape through the soil and keep it implanted there. Tine C has the best draught requirement but will only lift the soil without adequately

loosening it. While tine B requires rather more draught power, it does scatter and crumble the soil more satisfactorily.

A chisel plough should cover the entire width of the tractor, i.e. working at least both of the tractor's wheel-tracks. "Strip" chisel ploughs have recently become available; these leave a strip in the centre of the implement untouched and so require less draught power. The left-over strip has to be tilled by the return pass. This involves a practical problem as it is difficult for the driver precisely to follow the (narrow) strip which has to be tilled.

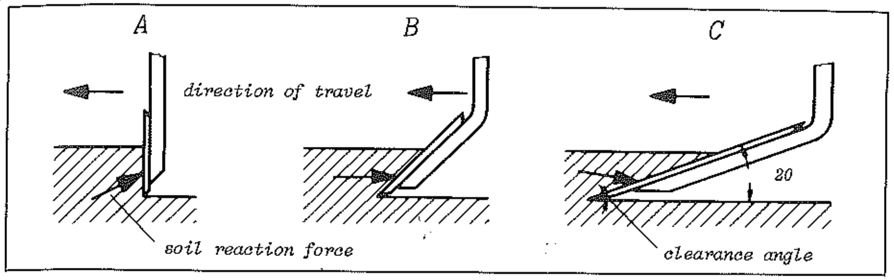


Fig. 37. Various angles of model tines, direction of the soil reaction forces: A: Vertical placement, B: Steep, C: Flat.

Under average conditions and with a speed of approx. 8 km/h the tractor power required for stubble tillage with a cultivator is around 26 kW per metre of width (30-35 kW with attachments). This increases to around 40 kW per metre (and occasionally to 60 kW/m) for deep tillage at 6 km/h. At the same speed the specific draught required for chisel ploughs is about half the power needed for mouldboard ploughs (about 5 N/m on heavy soil).

The appropriate lift angles are around 30 degrees for heavy chisel ploughs and up to 60 degrees for cultivators.

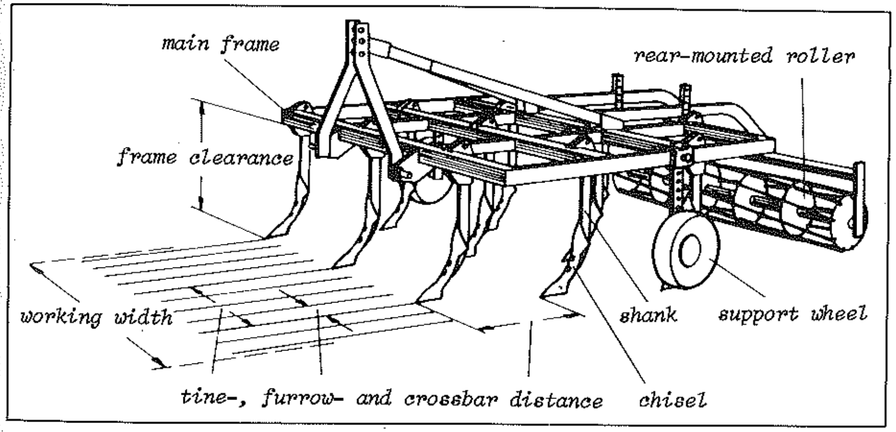


Fig. 38. Parts of a chisel plough.

2.3.4 Description Of The Implement And Tools

The basic frame (Fig. 38) is made of steel (flat, profiled or square tubes). The rigid, spring loaded or spring tines are mounted on this frame. They are placed in 2 to 4 staggered rows on fixed welded steel clamps or adjustable flanges. The depth is controlled by the supporting wheels or rear-mounted tools.

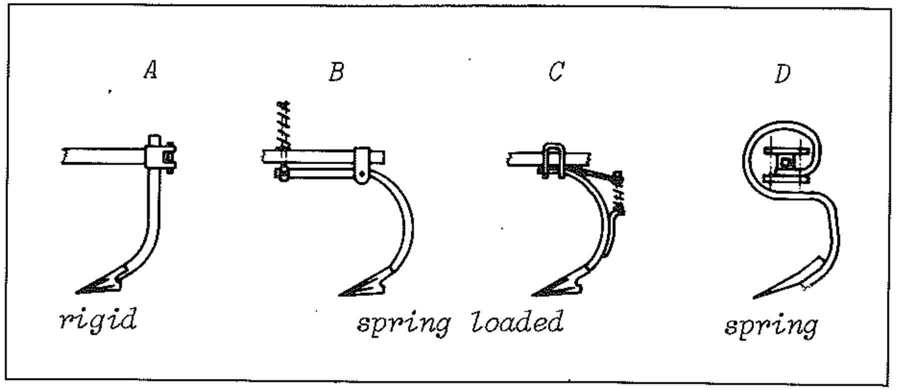


Fig. 39. Chisel tine shapes.

Rigid tines (Fig. 39A) - often fitted with a shearbolt for protection against stones - are made of high-carbon steel and are straight or slightly curved and angular to produce a chopping action. Rigid tines mounted at a smaller angle are particularly suitable for deep tillage.

Flexible tines (Fig. 39D), manufactured mainly from a heat-treated steel-nickel alloy, are flattened and slightly curved to allow diversion around obstacles. They are usually less suitable tor deep tillage.

Spring loaded tines (Figs. 39B and C) are hinge-mounted on the frame and cushioned by spiral springs.

The main technical data of chisel ploughs are:
Number of tines, number of rows of tines (=number of crossbars), distance between tines, distance between furrows, distance between crossbars, working width, frame clearance (height) and the consequent working depth.

In practice, 25 cm is often used as the furrow distance (the greater the working depth, the wider the distance between furrows).

The minimum distance between tines on one bar should be 60 cm because of the risk of choking (deep tillage). Correct matching of the number of tines, working width, distance between furrows, number of rows of tines and the distance between tines is essential for good performance (see Figs. 35 and 38). The number of tines, rows of tines and effective distance between tines are determined for a given distance between furrows (25 cm), working width and minimum tine clearance (60 cm). For a 25 cm gap between furrows a chisel plough should have 3 rows of tines so that clogging caused

by too narrow clearance of the tines cannot occur. This means, for instance, that 13 tines are required for a working width of 3.25 m. It is essential for the tines to be placed symmetrically on the frame to prevent the implement from being pulled to one side. The distance between the rows of tines should be at least 70 cm to ensure a free flow of soil and plant material.

A simpler form of chisel plough is the single-bar, two-row type (Fig. 40). Its frame (for 3-point linkage) consists of one heavy hollow bar with a headstock. Two alternating types of tines are attached to that bar: straight tines pointing forwards and tines with the same angle of attack but with a wide loop at the top, curving backwards. The resulting distance between rows is about 40 cm.

A similar type of toolbar, equipped with one row of tines, is suitable for rear-mounting of p.t.o. driven equipment. Like the rotating or oscillating hoe, this type is also used in a special combination with rotary tillers (see Chapter 11.2).

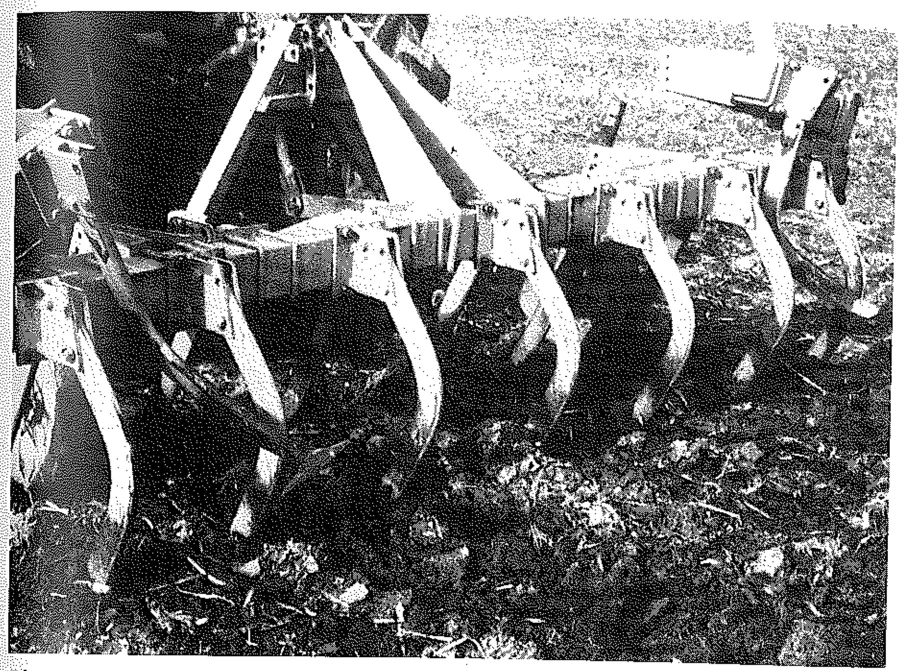


Fig. 40. One-bar, two-row chisel plough.

The height of the frame should not be less than 70 cm. Supporting wheels may cause choking when they are placed between tines and so they should be mounted on the outside of the frame or run in front of the tines (with sufficient clearance) on the untouched soil.

Tines are equipped with various types of chisels according to the intended use (Fig. 41). Stone protection devices, as shown in Fig. 42, should prevent breakage on soils containing many rocks or on extremely hard soils. These devices also help to keep the implement at the desired depth because only the individual tools will be diverted from obstacles, and not the entire frame.

Depending upon their size, chisel ploughs are designed as trailer, semi-mounted or mounted implements. The working width of mounted implements is between 2 and 6.5 m. Trailer (lighter) implements can cover up to 12 m. The heavier implements have an articulated frame with wings (outriggers) and supporting wheels which can be folded hydraulically for transport. Depths between 35 cm and 60 cm can be reached depending upon the type of implement.

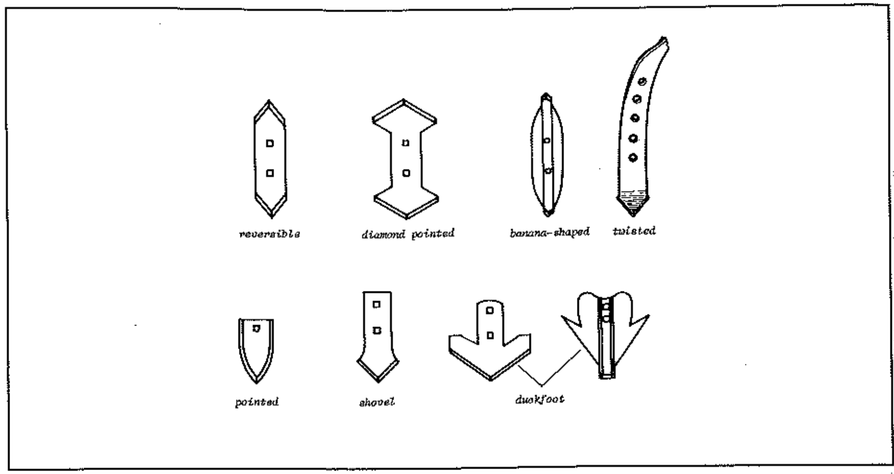


Fig. 41. Chisel shapes.

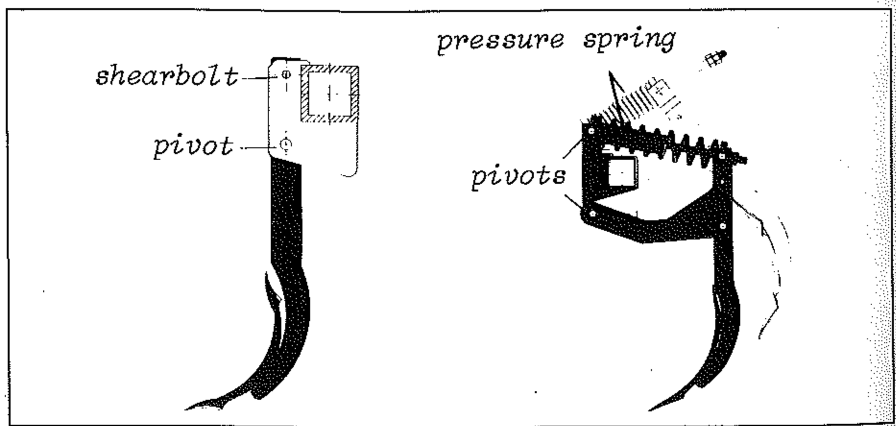


Fig. 42. Overload protection devices.
left: shear bolt, right: compression spring.

2.3.5 Adjustments, Operation

2.3.5.1 **Chisels** - On most implements the chisels can be changed in keeping with the operating conditions. They can often be reversed after one side has worn out.

2.3.5.2 **Distance Between Tines And Furrows** - On some types the tines are mounted by adjustable flanges on the main frame, allowing adjustment of the tine and furrow distance.

2.3.5.3 **Working Depth** - The working depth is usually controlled by the supporting wheels (by changing bolts on light implements and hydraulically on the larger types) or by rear-mounted tools. The use of the depth control setting of the tractor's hydraulic system (when no supporting wheels are used) has not proved successful. The maximum depth is limited by the height of the frame (sufficient clearance).

2.3.5.4 **Tillage Intensity** - The tillage intensity depends upon the speed, the ratio between the distance and depth of the furrows, the type of tines, the angle of attack and the shape of the chisels. The intensity can be considerably increased by repeat working (crosswise) and by using rear-mounted attachments. Under favourable conditions the chisel plough can also be used for direct drilling when combined with rear-mounted tools (levelling, crumbling and even p.t.o. tools) and a sowing machine. A rod weeder can be mounted on the last row of tines on some types of chisel ploughs for better weed control.

2.3.5.5 **Maintenance** - Mounted implements can be fitted with quick-coupling devices. The operation is simple and can be performed by one man. The driver has to get off the tractor to make any adjustment on the actual chisel plough. Chisel ploughs for deep tillage and also standard cultivators are very sturdy and do not need much repair. Wear will occur not only on the chisels but also on the overload protection devices. Servicing is limited mainly to lubrication of the supporting wheels and the adjustment devices for rear-mounted tools.

2.3.6 Technical Data

Heavy chisel ploughs

Frame height	60-90 cm
Working width	up to 14 m

Working depth	up to 60 cm
Power required	20-60 kW/m (27-82 hp/m)
	5-10 kW/tine
Distance between furrows	20-37.5 cm
Distance between tines	55-90 cm
Number of tines	5-39
Number of rows (crossbars)	1-4
Distance between crossbars	up to 90 cm
Overload protection devices	shearbolts, spiral springs
Weight	120-450 kg/m

Light cultivators

Frame height	from 30 cm
Working width	up to 20 m
Working depth	15-20 cm
Power required	7.5-11.5 kW/m (10-15 hp/m)

2.3.7 Literature

See literature of chapters 1 and 2.0.

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2.4 The Rotary Tiller

2.4.1 Use And Assessment

The rotary tiller (Fig. 43) is used for:
- stubble tillage (especially for intermediate crops) including working in straw (mulching),
- working in organic material,
- working in cattle manure,
- mechanical weed control,
- seedbed preparation,
- puddling in paddy rice production systems,
- sowing in one operation when combined with sowing equipment,
- strip cultivation in row crops (also in combination with ridgers),
- grassland and wasteland clearing,
- road reconditioning.

In principle, extreme caution is required when using the rotary tiller in the tropics and subtropics. On sloping land in particular the pronounced pulverization effect may lead to slaking of the surface, erosion, rapid decomposition of organic matter and, possibly, more rapid drying-out of the soil.

There are far fewer objections to the use of the rotary tiller in irrigated farming (especially in the case of surface irrigation). The special merits of this implement when used for paddy rice-growing will be given more attention in Chapter 6.

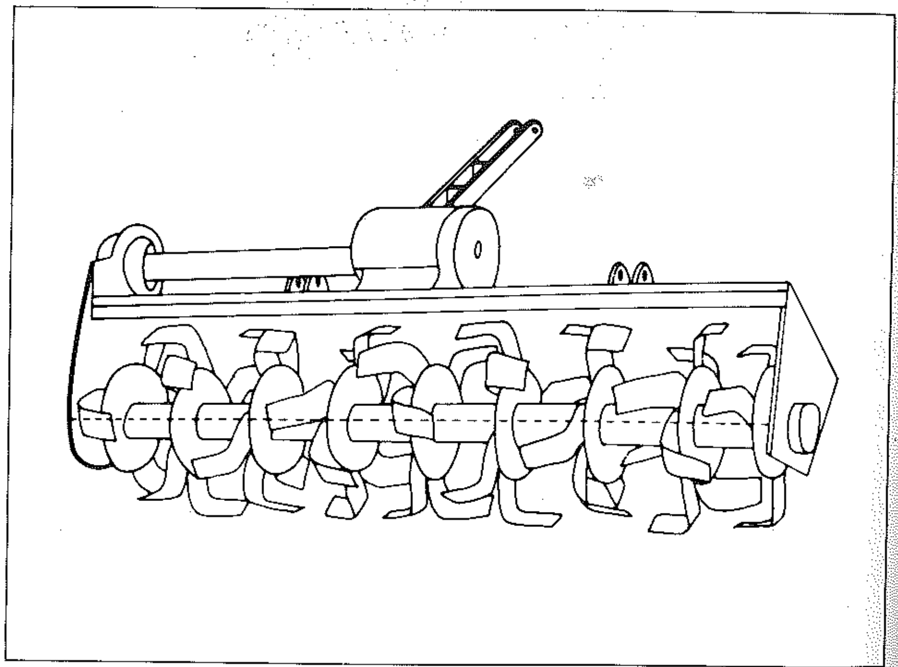

Fig. 43. Rotary tiller.

Rotary tillers have the following advantages:
- the desired crumbling and mixing can be achieved under a wide range of soil conditions by adjusting the number of revolutions and the forward speed. In many cases only one pass is necessary to produce a seedbed (time saving, sowing at the correct time, fewer wheeltracks);
- they are very suitable for working in organic material, mulching, grassland clearing (accelerating decomposition);
- stubble tillage is still possible on hard firm soils where disc or rotary harrows cannot be used. This operation does, however, impose heavy demands on the machine, tractor and driver and causes considerable wear;
- they produce hardly any tillage or compaction soles;
- the power transmission is very efficient (about 80%) because of the p.t.o. drive (a plough is only about 50%). They cause hardly any slippage of the tractor's driving wheels and so uphill working is possible;
- their short length removes less load from the front axle of the tractor;
- they can be combined with mounted sowing machines (very short sowing time);
- they are very reliable.

The disadvantages of rotary tillers are:
- the power required per volume of manipulated soil is high compared with a (chisel) plough because of the operating intensity;
- when the tillage intensity is too high (excessive rpm, low speed), the operation may cause surface slaking, crusting and soil erosion;
- accelerated decomposition of organic matter can be expected;
- the capacity is not always satisfactory, especially for deep tillage; with a working width of 2.75 m the capacity is only 1 ha/h for stubble tillage;
- a serious strain is imposed on the tractor p.t.o. and drive system on hard stony soils;
- the driveshaft must match the tractor's p.t.o. shaft (profile, length); adaptors are sometimes necessary.

2.4.2 Functioning

The rotating blades on the main shaft of a rotary tiller cut the soil when moving downwards. The blade's course is cycloidal because of the forward travel and it cuts wedge-shaped slices from the soil (Fig. 44). These slices are thrown backwards against the hood and trailing screen which causes further crumbling. When the shaft is driven from the centre, a narrow untilled ridge is left (a tine is sometimes needed to break up this ridge). When the drive is mounted on one side of the machine, its protection shield determines the maximum depth (generally up to 15 cm or up to 30 cm on special machines). The preferable working depth is between 5 and 15 cm. For seedbed preparation, however, the tilling depth should not exceed 10 cm.

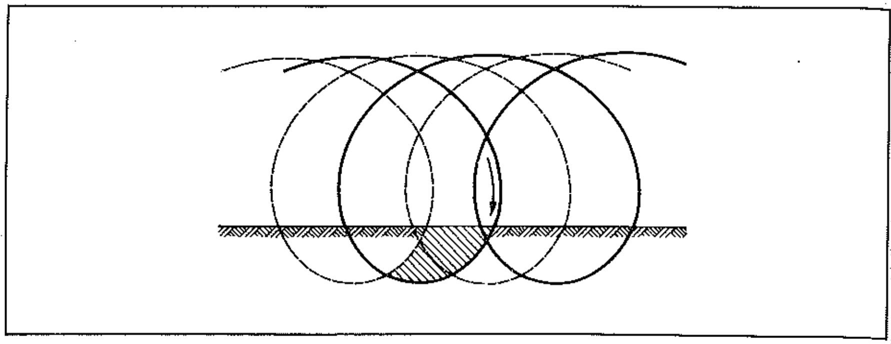

Fig. 44. Cycloidal paths of points on the cutting edge of two consecutive knives of one working set of a rotary tiller.

The tractor wheel-tracks can be loosened directly by off-set mounting for narrow machines or by using machines wide enough to cover both tractor-wheels. The number of revolutions of the tiller shaft (100-300 rpm) can be adapted to the travelling speed (up to approx. 6 km/h) and the soil conditions. In many cases, therefore, seedbeds can be prepared in one single pass (time-saving, fewer tracks), especially when the machine is fitted with a crumbling roller.
The axle revolutions and forward speed must be synchronized to achieve the desired crumbling rate. Depending upon the shape of the blade, a clearance angle must be left between the plane of the blade and the tangent to the cutting trajectory (Fig. 45). If this angle is too small, the cutting surface of the soil will be smeared.
As the number of blades along the periphery is increased (2-4-6), the tillage becomes more intensive.

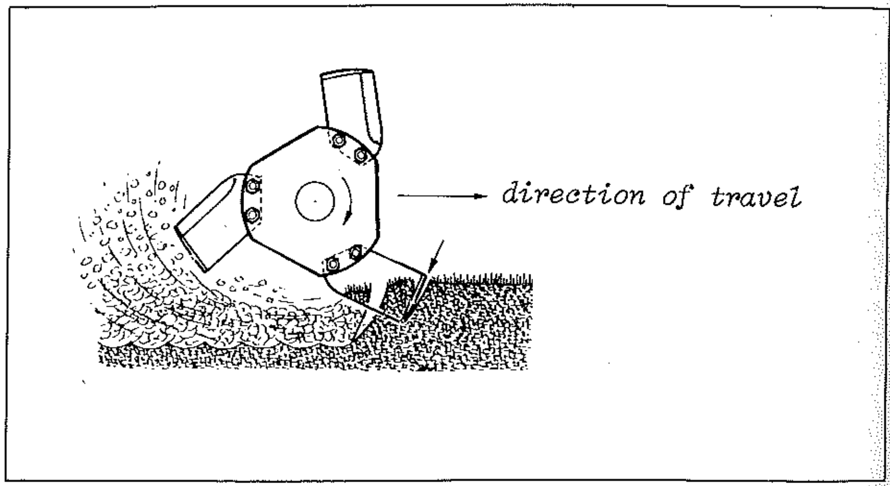

Fig. 45. Clearance angle of rotary tiller knives (indicated by arrow).

The rotary tiller is very efficient for chopping and mixing (see Fig. 17), especially when it is fitted with standard (L-shaped) blades. Organic matter can be well worked in if it is evenly distributed over the surface. When there is a risk of wind or water erosion or in quick-drying conditions, the working depth should be shallow and the tilling intensity as low as possible so that the surface is left as rough as possible.

The infiltration capacity of the soil can be improved by shallow tillage but only if it is not limited by the infiltration rate of the subsoil (e.g. owing to tillage or tractor tyres). Nonetheless, a rotary tiller should never be used merely to improve infiltration. The pronounced loosening of the soil by a rotary tiller causes considerable decomposition of the organic matter and also considerable nitrification of the nitrogen bound to that material (important in a closely integrated crop rotation).

Strips can be cultivated for row crops (e.g. potaties, cotton) by removing various units; this reduces the organic matter decomposition and the risk of erosion. The strip system can be employed for sowing (cereals, sugarbeet, cotton) and for crop protection operations (weeding, ridging, etc.).

Propagation of rooted weeds by partitioning of the rhizomes can be prevented (in dry weather) by tilling more than once with a rotor revolving at high speed.

A special model - the rotary tiller with reverse rotation - permits satisfactory inversion and crumbling in one pass for grassland clearance.

Owing to the thrust action of a rotary tiller (excluding the reverse rotation type) hardly any slippage occurs by the tractor drive wheels (no smearing of the soil). A rear-mounted packer is often used for levelling and packing the soil and for improved depth control.

Rotary tillers have recently been produced with passive soil-loosening tools (rippers, chisels) mounted either in front of or behind the rotor and operating below the (rotor's) working depth. These implements make it possible to combine shallow crumbling with deep loosening.

2.4.3 Linkage And Drive System

Larger rotary tillers are generally suitable for 3-point hitch linkage (categories I - III, depending upon the power requirement) and only rarely for use as a trailer implement. The tillage operation is performed with the hydraulic system in free-floating mode since the system is not needed for depth control. Two adjustable depth wheels or skids or a rear-mounted roller control the working depth. The lifting capacity at the ends of the tractor's lower links should be more or less twice the weight of the implement. The centre of gravity is located close to the tractor.

Many rotary tillers can operate in an offset position so that they can be adapted to the track width (Fig. 46). A device is available for work in orchards which shifts the implement sideways and back when a tree is encountered.

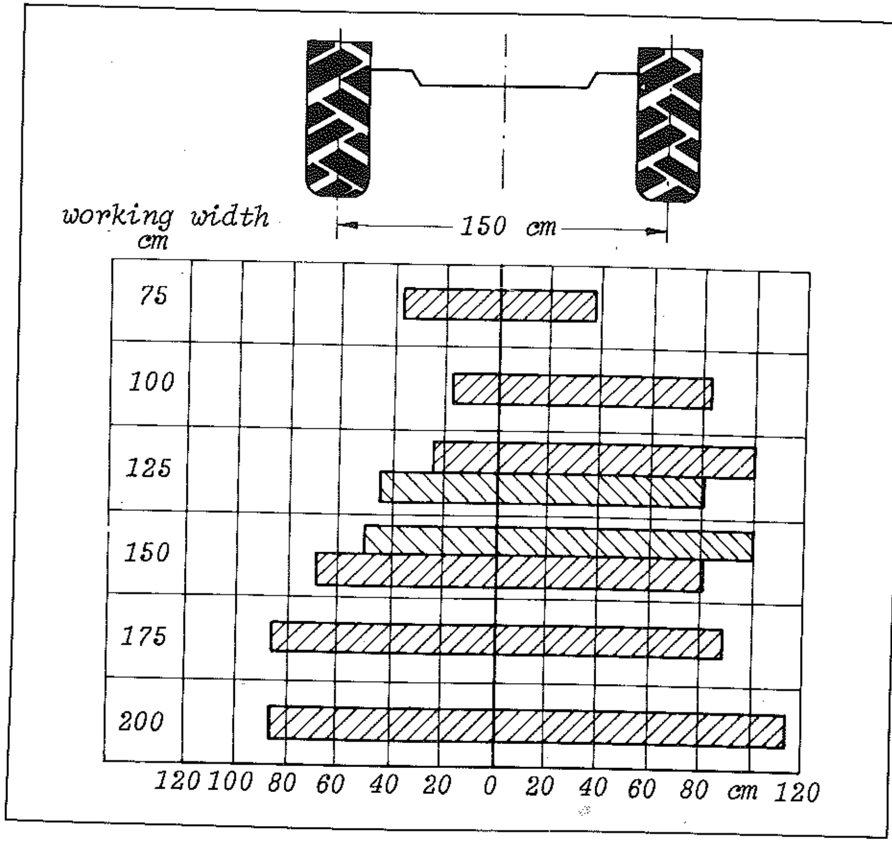

Fig. 46. Working widths related to the center of the tractor for rotary tillers of 0.75 - 2.00 m wide.

The implement is driven by the p.t.o. at 540 or 1000 rpm. The higher rpm is now commonly used for the larger rotary tillers to save the drive system and bearings. The gear-wheels in the gearbox usually have to be (inter) changed when switching from 540 to 1000 rpm.

Pto- and drive shaft should have the same spline profile and the driveshaft should be the correct length (when at working depth the telescoping joints of the shaft should overlap for at least 200 mm; when lifted, at least 20 mm clearance should be left to allow for further shortening of the shaft). At working depth the universal joints in the drive shaft should have a maximum angle of 30 deg. An overload safety device is strongly recommended, especially on hard stony soils.

Rotary tillers require power (almost entirely through the p.t.o.) of 25-35 kW (approx. 35-45 hp) per meter of working width for primary tillage at a speed of 3-4 km/h. This reduces to 18-22 kW/m (approx. 25-30 hp) on ploughed soils.

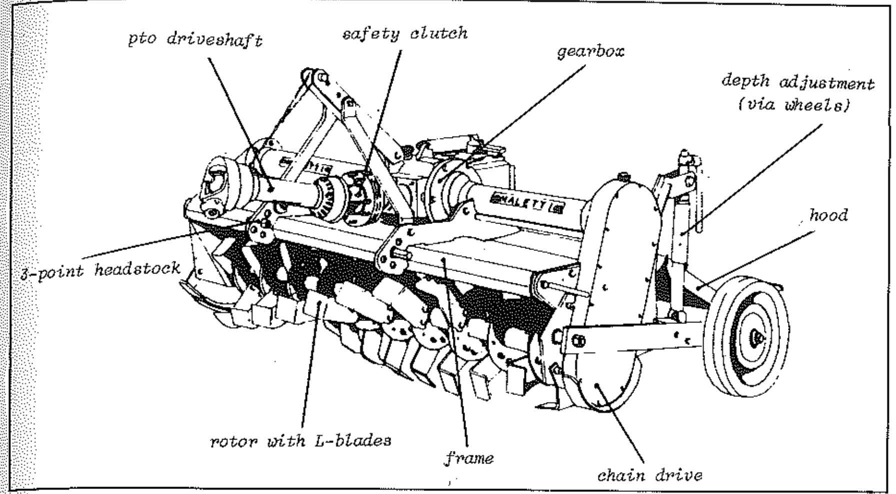

Fig. 47. Rotary tiller.

2.4.4 Description Of The Implement And Tools

A frame (Fig. 47) supports the main shaft which is mounted across the direction of travel and supported by bearings, either in the centre or at both ends. The rigid soil-engaging tools (blades or knives, Fig. 48) are mounted on separate flanges (interval > 20 cm) each with up to 6 tools arranged in "working sets". The blades are set to the left and right in an equal number of pairs (2-6), except for the sets on the sides. The complete unit made up of shaft and tools is called the rotor. The blades are arranged in a spiral pattern to provide smooth operation: only one blade should hit the soil at a time.

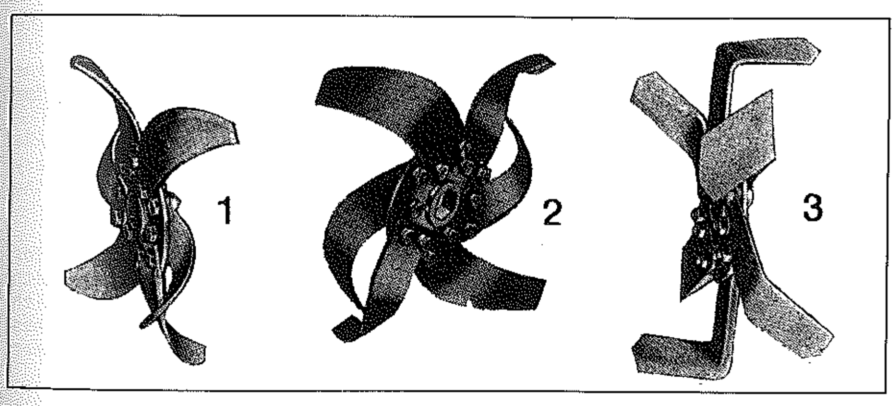

Fig. 48. Working sets with:
1. *Cutting blades for light to heavy soils,*
2. *Crumbling blades for light to medium soils (fine tilth),*
3. *Mulching blades to incorporate straw, farmyard- and green manure.*

The rotor is driven by chain transmission or gear-wheels from the centre or one of the sides. There is usually a gearbox and overload safety device between the tractor drive system (p.t.o. shaft and driveshaft with universal joints) and the drive system of the rotor.

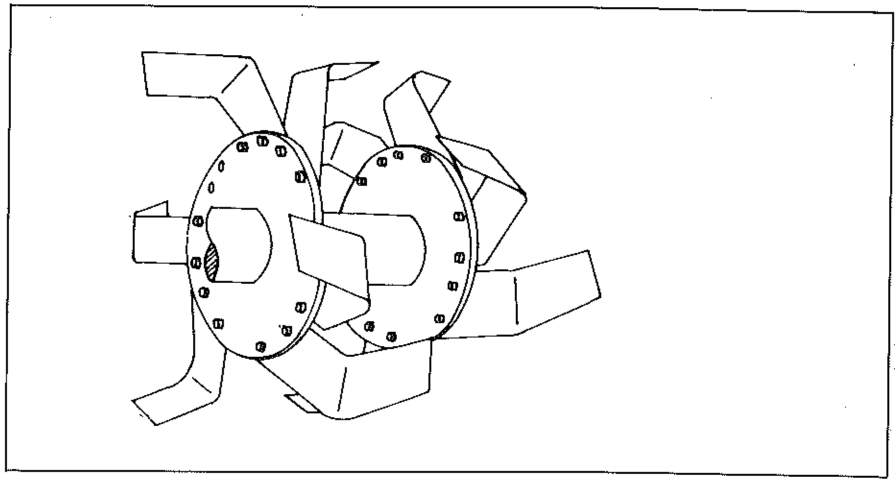

Fig. 49. Working sets.

The rotor usually rotates in the same direction as the tractor-wheels (concurrent revolutions, Fig. 50A).
Reverse-revolution rotary tillers (Fig. 50B) are also available. On both types a hood is used for additional crumbling of the soil aggregates and for guiding the flow of soil material produced by the rotor (protection against flying stones, etc.). One or more trailing screens extending over the entire working width may be used to level the soil surface.
A screen of iron bars between the rotor and hood is a special feature of the reverse-revolution type (Fig. 50B). This screen separates the coarse soil material, sods, trash, etc. and deposits them before and below the fine material which passes through the bars. This machine is frequently used for grassland renovation when a seedbed for resowing is made in one pass.
The rotary tillers' working depth can be adjusted by gauge wheels or skids or by using a packer. Because of their short length rotary tillers are very suitable for attaching tools to the rear (rollers to compact or crumble the soil) and for mounting sowing equipment (direct drilling).

The rotor can also be fitted with tines (Fig. 77) or spikes (Fig. 42) for secondary tillage on ploughed land. Rotary tillers are often combined with other implements for primary tillage, especially implements fitted with rigid tines (combination of chisel plough and rotary tiller). The tines produce deep loosening of the soil while the rotary tiller performs more intensive tillage on the surface.

The spike rotary tiller is commonly used for making ridges in one pass; special ridging units or shapers are mounted at the rear. The machine can be used later for maintenance (re-ridging, strip tillage) by removing certain working sets.

Rotary tillers are designed as mounted, trailer or self-propelling (power tillers, see chapter 6.2) implements.

2.4.5 Adjustments, Operation

2.4.5.1 Working Depth - The depth may be varied from 0 to 25 cm by adjusting the gauge wheels or skids by means of spindle or bolts. The depth can also be set by transferring the load to a packer (when mounted). The shielding of the drive system will control the depth on very dry and hard soils. Sickle-shaped blades work at greater depths than universal blades. Adjustment of the tractor's lifting arms (spindle) makes it possible to level the machine in a lateral direction.

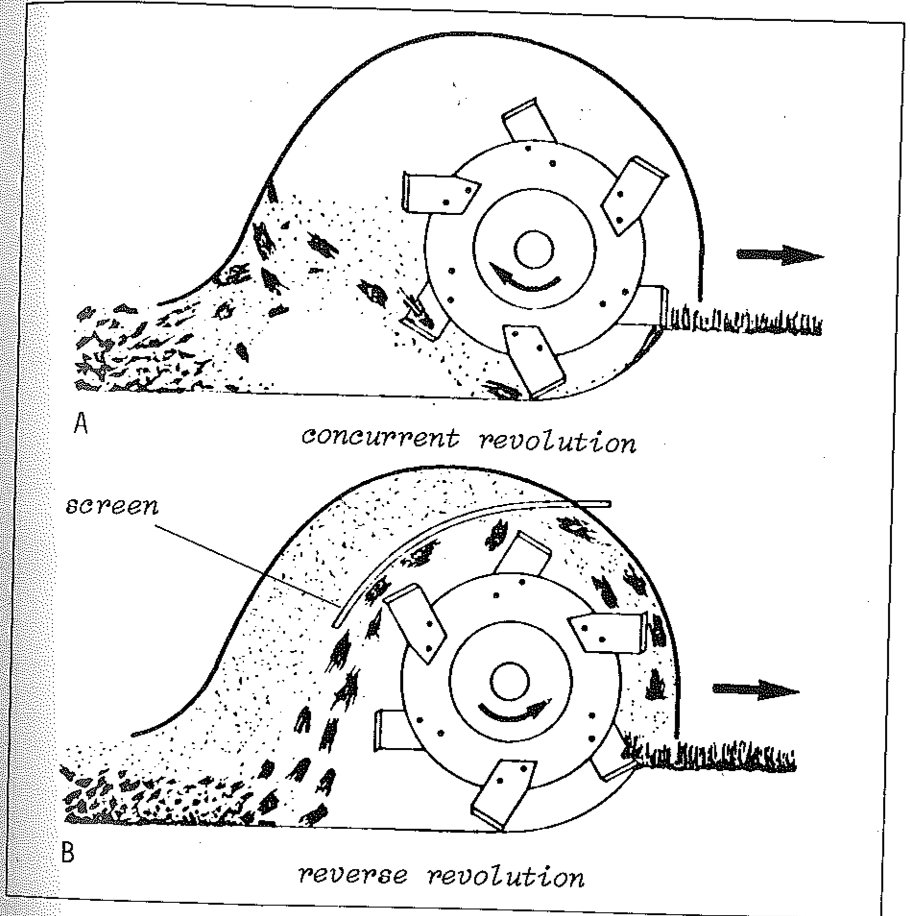

Fig. 50. Concurrent revolution (top) and reverse revolution (bottom) rotary tiller. - Source: Heege.

2.4.5.2 **Tillage Intensity** - The tillage intensity (bite length, number of cuts per square meter) depends upon the rotor speed (usually between 100 and 300 rpm) and the forward travel speed (Fig. 51) as follows:

- low rotor speed and high forward speed: leaves clods and preserves the soil structure;
- high rotor speed and low forward speed (1.0-1.5 km/h): intensive tillage;
- a very high rotor speed requires a great deal of power from the p.t.o. (the increase is more than proportional) and imposes a heavy strain on the drive system;
- the rotor's peripheral speed should be about three times the forward travel speed;
- the hood is used for additional crumbling;
- the trailing screen greatly influences the resulting tilth: the lowest position gives the greatest intensity;
- rear-mounted rollers are used for re-compacting the soil, controlling the depth and, sometimes, for levelling or final crushing.

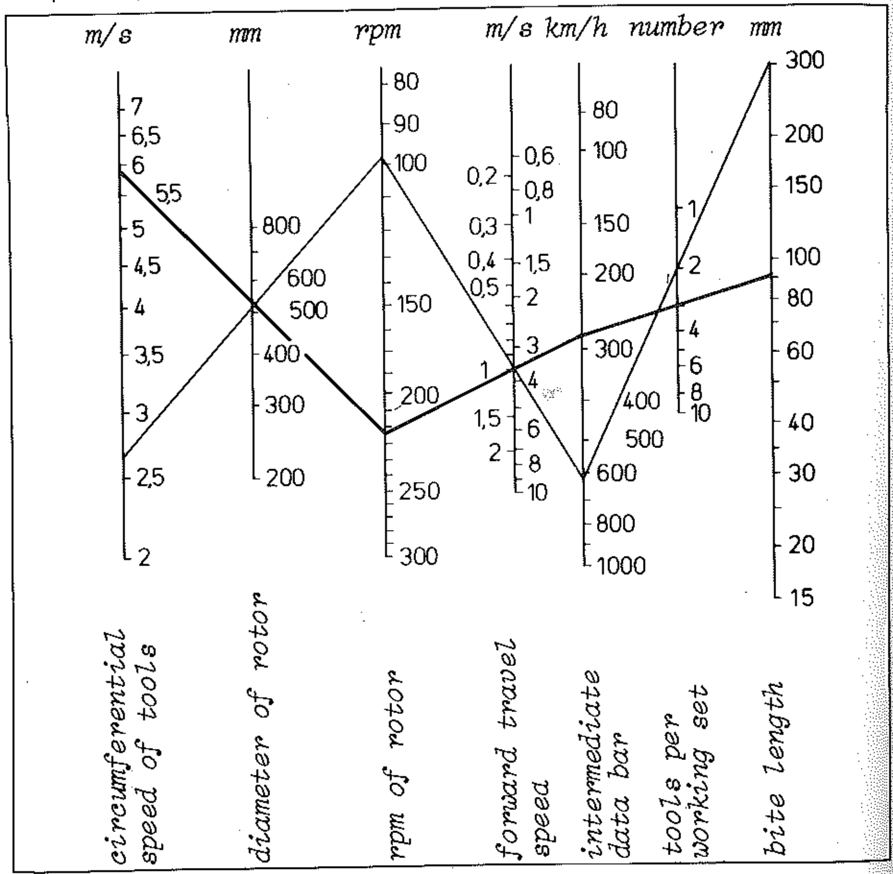

Fig. 51. Bite length as a function of design and adjustment for a rotary tiller. Based on the required bite length (extreme right axis), the possible combinations for adjustment can be found.

2.4.5.3 **Operation** - Rotary tillers can easily be mounted and adjusted by one man; a quick-coupling device can be used. A rotary tiller does not require high skills from the driver. Clean working can be achieved by allowing an overlap (about 10%).

2.4.6 Technical Data

Working width	up to 4.5 m
Working depth	5-15(30) cm
Rpm of p.t.o. drive	540/1000
Travel speed	up to 6 km/h
Power required	from 20 kW (better is 30 kW) per metre of working width
Gearbox (rotor rpm)	up to 10 steps
Rotor's peripheral speed	4.0-7.5 m/s
No. of blades per set/total	2-6/up to about 132
Distance between sets	from 20 cm; up to 45 cm when used behind loosening tines
Weight	350-500 kg/m
Safety devices	friction clutch (single or multiple disc type)
Packing/crumbling roller	400 mm in diameter.

2.4.7 Literature

See literature of chapters 1 and 2.0.