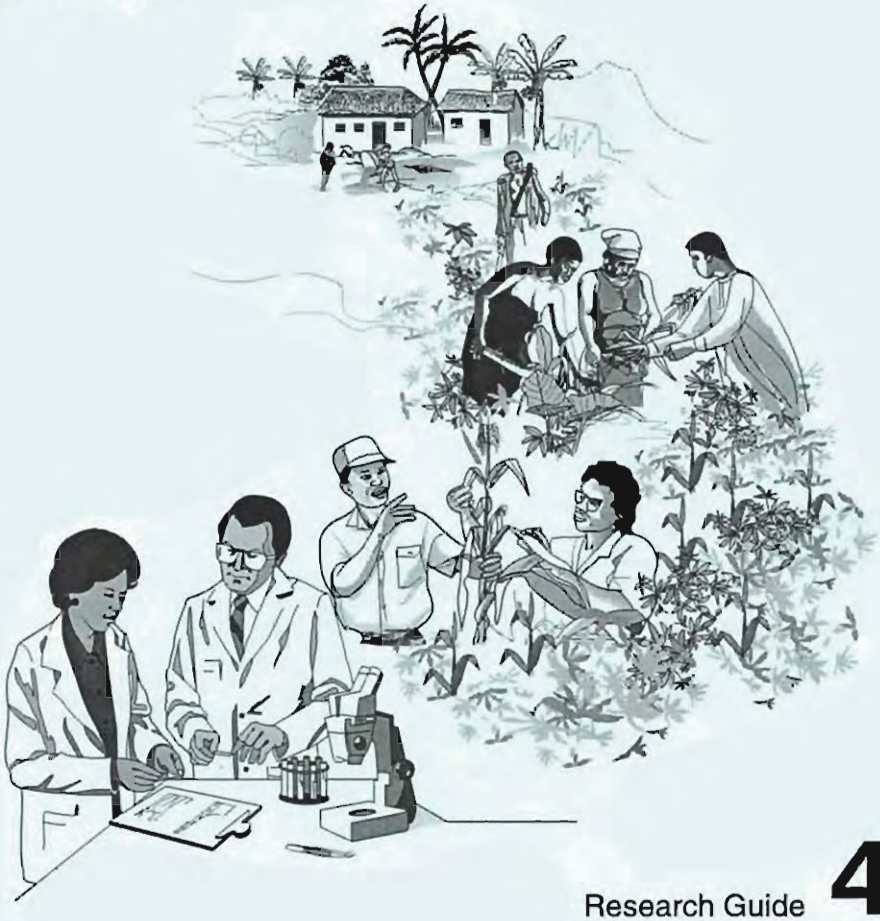
International Institute of Tropical Agriculture (IITA)

Tractor design and operation for research stations

Paul V. Hartley



Research Guide 4

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Tractor design and operation for research stations

Objectives. This guide is intended to enable you to:

- describe the evolution of tractors
- categorize tractors
- describe types and functions of engines, transmissions, hydraulics, power take off units, and auxiliary modules
- operate tractors safely
- maintain tractors

Study materials

- Slides showing evolution and type of tractors.
- Engines, transmission, hydraulics, power take off, auxiliary modules.
- Maintenance equipment and tools.

Practicals

- Demonstrate the use of tractors.
- Demonstrate types and functions of tractor components.
- Practice maintenance of tractors.
- Discuss and demonstrate safety measures.

Questions

1 What were the main disadvantages of the steam traction engine?
2 Name the 6 main categories of tractors in use today.
3 What is the most common type of tractor?
4 What is the most commonly used fuel in agricultural engines?
5 What is the function of the power take off?
6 What is the function of the hydraulics?
7 What is the first concern in operating a tractor?
8 What are the basic gauges found in a tractor?
9 What conditions should you check daily?
10 What is included in major servicing?
11 What is the value of maintenance records?

Tractor design and operation for research stations

Abstract. The agricultural tractor has passed through a long evolution from the early steam-powered machines to the modern petrol- and diesel-engine tractors of today. The hydraulic system, power take off, and auxiliary modules have greatly extended the capabilities of tractors. Today, the reliability of tractors depends almost entirely upon proper maintenance. However, tractors are inherently dangerous and must be operated with care.

1 Evolution of tractors

The modern tractor evolved through the development and adaptation of earlier forms of mechanical land power. Development began when farmers recognized the need for more reliable power than draft animals.

The steam traction engine evolved from the steam locomotive. The steam traction engine was heavy and sank in fields that were even slightly soft, so it was restricted to highway transport and powering threshing machines at harvest. Eventually, the steam traction engine was equipped with a cable drum that could winch a plow or cultivator across the field, and this was the nearest it ever came to the land.

The steam traction engine was too heavy, specialized, and expensive for most farmers. Lighter tractors became possible with the manufacture of reliable internal combustion engines around 1900. The first truly mobile tractors were powered by these engines and were light enough to go into the fields.

Though the design and reliability of tractors improved over the next 40 years, the tractor was still a mechanical 'draft animal', pulling plows, cultivators, or other equipment.

The situation changed in the early 1930s when an Irish engineer named Harry Ferguson designed a hydraulic system for 'carrying' implements. Before this, implements were dragged behind the tractor. Ferguson's system greatly improved traction by transferring the implement's weight onto the back wheels of the tractor.

Though Ferguson's hydraulic system greatly improved tractor performance, it did not improve operator safety.

Around 1985, it became mandatory to fit tractors with 'roll over protection structures' to lessen the high risk of fatal injury if the tractor rolled over.

As manufacturers seek better productivity through improvements in transmissions, tires, and engine power, some tractors have become heavy again. To avoid soil compaction problems, modern tractors are sometimes '4 wheel driven' (4WD), with the weight evenly distributed over the four wheels. Dual or twin wheels are sometimes fitted to further reduce ground pressure.

However, with all the developments in the last hundred years, most tractors today still look much like small steam traction engines. Developmental change has been restricted mainly to setting up gantries to span blocks of fields at each pass. Change has been slow not because tractor designers and engineers have been idle, but because manufacturers are reluctant to make expensive changes to their production lines.

The future will see more sophisticated tractors with greater reliability, maneuverability, comfort, and safety. Gradual evolution in design is more likely than radical change. Currently, faster highway towing speeds and improved braking systems are being developed.

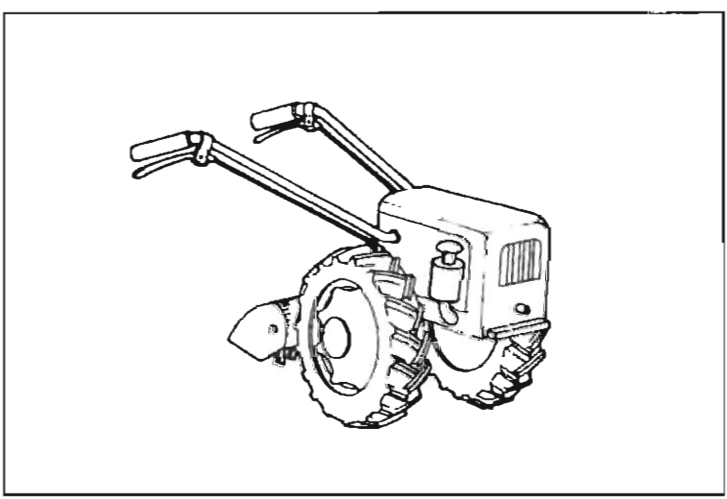
2 Tractor design and layout

Tractors are divided into 6 main types:

- 2 wheeled tractors
- 4 wheeled, 2 wheel driven (2WD) tractors
- 4 wheeled, 4 wheel driven (4WD) tractors
- 8 wheeled, 8 wheel driven (8WD) tractors
- tracked or 'crawler' tractors
- special purpose tractors

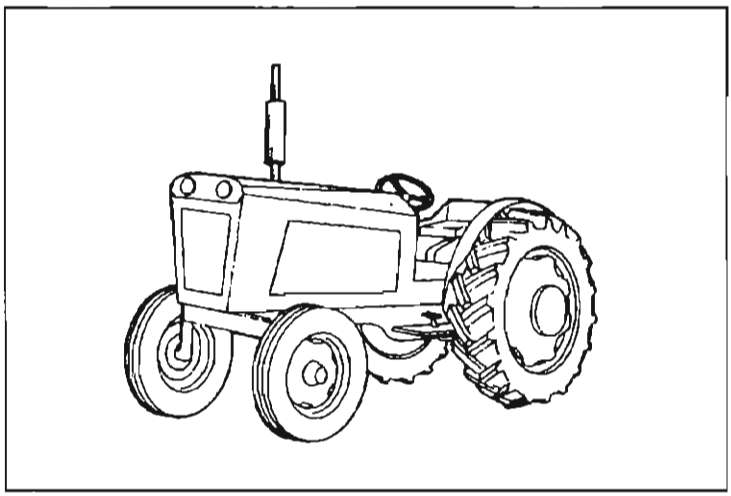
Two wheeled tractors. Two wheeled tractors are often called 'walking tractors' (Figure 1). The small hand held units with rotary cultivators are usually driven by petrol engines. Larger units are often coupled to 2 wheeled trailers and driven by diesel engines. Engines of 5–10 horsepower (HP) are common.

Figure 1. Two wheeled tractor (walking tractor).



Four wheeled, 2WD tractors (Figure 2). Four wheeled, 2WD tractors are the most common type of tractor. The two rear wheels supply power. The front wheels are much smaller and are used only for steering. Engine power ranges from 25 to 120 HP.

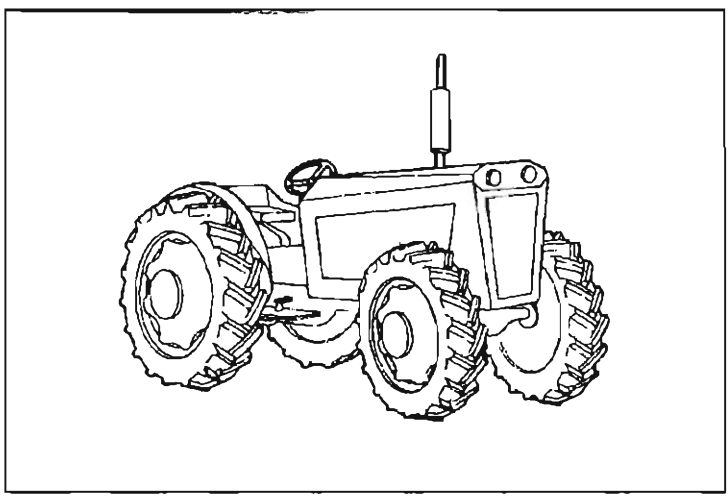
Figure 2. Four wheeled, 2WD tractor.



Four wheeled, 4WD tractors (Figure 3). The 4 wheeled, 4WD tractor is similar to the 4 wheeled, 2WD tractors, but all 4 wheels can be powered for better traction. The front wheels are half the size of the rear wheels. 4WD tractors usually have power ratings of 70 HP and above, although some lower horsepower units are made for special purposes.

Eight wheeled, 8WD tractors. The 8WD tractors are the top of the range in terms of weight and power. They avoid soil compaction and wheel slip by distributing weight and power over 8 wheels. They are jointed in the middle, and 1 axle is mounted to each of the jointed halves, with both axles driven. Each axle has 2 dual wheels at each end, or 4 wheels per axle. 8WD tractors usually have engines of 200 HP or more.

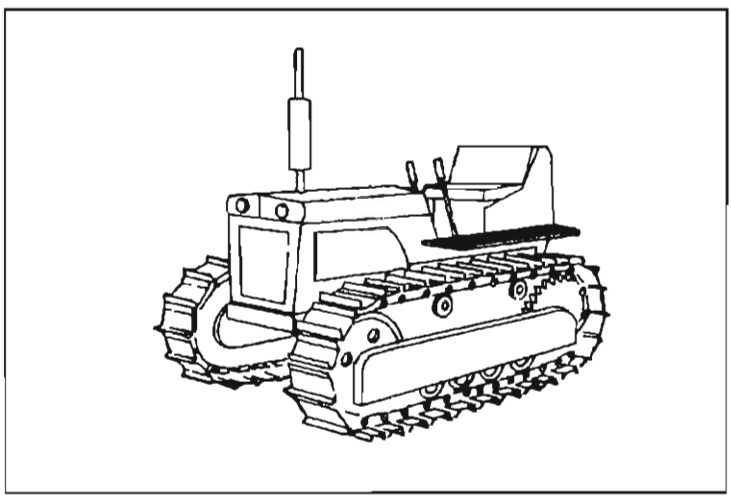
Figure 3. Four wheeled, 4WD tractor.



Tracked or 'crawler' tractors. Tracked tractors are equipped with tracks instead of wheels (Figure 4). They are generally used on farms where soils are difficult to cultivate, such as heavy clays, or where seasons are shorter and wet conditions predominate. More power can be transmitted to the drawbar than wheeled tractors.

Maintenance costs are however higher than for wheeled tractors. Also, unlike wheeled tractors, they must be transported from field to field by a 'low loader'. Recently, a tractor manufacturer designed a high powered, high speed tracked tractor that runs on rubber tracks and can be driven on the road. This model may make the tracked tractor more popular in the future. Tracked tractors have power ratings of 65–700 HP.

Figure 4. Tracked or 'crawler' tractor.



Special purpose tractors. The agricultural tractor is sometimes modified for use under special conditions where the standard type is not suitable.

The narrow tractor is a basic small tractor which has been modified to pass through the narrow rows of soft fruit trees and vineyards.

The high clearance tractor is usually a standard tractor which has been elevated to give more clearance over advanced stage crops for spraying or fertilizer broadcasting.

Light, low HP, 4WD tractors work in rice paddies, where the combination of light weight and 4WD is desirable.

Other special purpose tractors provide engine and transmission facilities for purpose-built machines, such as pipe layers, drainage machines, and mechanical harvesters.

3 Engines, power transmission, power take off

Engines. Diesel (automotive gasoil) is the most commonly used fuel in agricultural engines. Petrol is generally confined to smaller tractors and crop handling equipment.

Petrol engines are usually small, single cylinder, air cooled units and are used to power 'walking' tactors. Multi-cylinder petrol engines are hardly ever used in agricultural equipment today. Their reliablility is reduced by having an electrical ignition system. Petrol too is extremely flammable and so safety margins are much less.

Diesel engines use compression ignition, where injected fuel is ignited by hot highly compressed air inside the cylinder. Diesel engines have a strong construction, are inherently simpler, and thus more reliable than petrol engines. They deliver power over a wider speed range and have more torque or lugging power at low speeds than petrol engines. Fuel economy is greater because of the higher power density of the fuel, but of course fuel consumption will increase with higher HP.

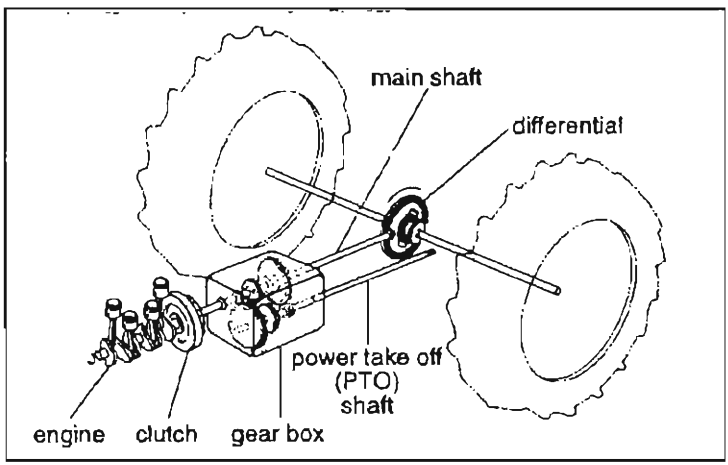
Tractor engines can be 3, 4, or 6 cylinder in-line engines, and then go to V-8 and V-12 configurations. Turbocharging is now very common, and enables greater power output from a given size of engine. However, if strict operating rules and servicing, especially oil changes, are not carried out, reliability of a turbocharged tractor engine will be seriously reduced. For developing countries, it is advisable to opt for a bigger sized naturally aspirated engine than a smaller turbocharged unit of the same power.

Power transmission. The tractor moves when engine power flows through the drive train to the driven wheels. The drive train consists of (Figure 5):

- clutch
- gearbox (sometimes called the transmission)
- differential
- power take off (PTO)
- drive shafts

Clutch. The clutch disengages the engine from the gearbox so the tractor operator can shift gears or stop the tractor. The clutch in most tractors is a dual unit that can pass power to both the gearbox and the PTO, which provides power to auxiliary implements.

Figure 5. Transmission system.



Gearbox. A gearbox is necessary to keep the engine at its most efficient operating speed while being able to vary ground speeds of the tractor. Also, it is not possible to accelerate the mass of a tractor and implement using high gears from a dead start, so a low gear is selected for starting and upward changes made as you get to the speed limit of that gear.

Most agricultural operations have an optimum speed to achieve the best result for the type of work you are doing. If you are going too slowly, you are wasting time and fuel, and if you are going too fast, the quality of work will decrease and you may be overloading or lugging your engine, which will shorten its life.

Generally, from experience, the driver will select a gear and set his engine speed for a particular implement before moving off in the field. He may find during the day that conditions improve or dry out and he can select the next higher gear, but in the evening conditions worsen again and he has to come down to the original gear or one lower. The engine is maintained at constant and most efficient speed, usually between 1500 and 2000 rpm.

Operations like crop spraying and fertilizer spreading require set ground speeds to achieve the application rate and precision required, while the engine is running at PTO speed to produce 540 rpm shaft speed, which is driving the chemical pump or spinning disks. This combination must not be varied or application rates will suffer. The engine's governor will take care of changes in slope in the field.

Because of the wide range of jobs carried out by tractors, a gearbox with many gears is required. Generally,

there are two boxes. The first—main—has 3 forward and 1 reverse gear; the second—range—has speed ranges, either 2 (low and high), more commonly 3 (low, medium, and high) or occasionally 4.

Forward first and reverse gears are usually opposite each other so you can shuttle between them for jobs like fore-end loader work. A gearbox may be described as a 12 x 3—this has 9 forward and 3 reverse gears arranged in three ranges. A 16 x 4 has 12 forward and 4 reverse gears in four ranges. Higher gears may have synchromesh for smooth changing at high speeds on the road. Lower gears do not need it as they are nearly always preselected before moving off in work.

Modern tractors can also have a power shift component where speed ranges can be changed on the move, that is, clutchless. However, they are more expensive and difficult and expensive to repair. For developing countries, a simple manual transmission is best.

Differential. After the engine power has passed through the gearbox, the differential sends it to the driven wheels. The differential allows the driven wheels to turn at different speeds, as when turning a corner.

In the case of a 4WD or 8WD tractor, power is also sent to the front wheels, which are equipped with their own differential.

To compensate for rear wheel slippage, the front wheels of 4WD and 8WD tractors turn slightly faster than the rear ones. These tractors must not be driven on the road in four wheel drive, because of excessive tire wear and damage to the drive train.

Power take off. PTO provides power to coupled or trailed implements such as mowers, sprayers, and cultivators.

The power for the PTO comes from the engine through the dual clutch. The two transmissions of power are usually independent. For example, an operator can stop or move the tractor without affecting the use of the PTO, or can stop the PTO yet still move the tractor.

Tractors under 100 HP use a PTO speed of 540 rpm, and larger units use a PTO speed of 1100 rpm. Some manufacturers of smaller tractors provide both speeds regardless of the HP rating.

The PTO may also drive hydraulic pumps for remote work (see Section 4).

Drive shafts. Drive shafts connect the other components of the drive train. For instance, the gearbox and differential may have a connecting drive shaft.

Ferguson's invention of the hydraulic 3 point hitch was probably the single most important improvement to the tractor. Before his invention, implements such as plows were simply dragged behind the tractor on a drawbar.

Basic hydraulic systems simply lift, hold, and lower implements. This is an improvement over dragging the implement, but will not assist the tractor in difficult conditions. More sophisticated systems provide draft, height, and depth control, allowing for quick response to different soil conditions.

The amount of power required to drag an implement through the soil can change as quickly as soil conditions change. A plow set to the correct depth for loamy soil may dig in too deeply as the soil changes to clay, and require more force. This may cause wheel slip or uneven plowing.

The hydraulic 3 point hitch system improves traction in 2 ways. First, it puts the dead weight of the implement in the soil onto the tractor's rear wheels, which increases traction greatly. Second, it varies the depth of the implement in the soil as soil conditions change. This means that the draft—the amount of effort required to pull an implement through the soil—stays the same even as soil conditions vary.

For example, if the plow digs in too deeply, the hydraulic hitch automatically raises the plow enough to compensate. Then, as the soil becomes easier, the hitch automatically lowers the plow. This automatic control of implement depth and draft greatly aids the tractor operator. It makes it possible to plow in conditions that would be impossible with a drawbar hitch or the basic hydraulic hitch.

Hydraulic systems also provide an external hydraulic oil supply or 'PTO' to power auxiliary hydraulic motors or cylinders.

Remote hydraulic implements. Remote hydraulic implements such as front-end loaders, diggers, and ditchers extend the usefulness of the agricultural tractor. These implements may be attached directly to the tractor or some distance away, connected by a hydraulic line.

Usually, the tractor's own hydraulic PTO powers the remote units. Some implements however, are equipped with their own hydraulic pump, which is driven from the tractor's mechanical PTO. These systems are generally more powerful.

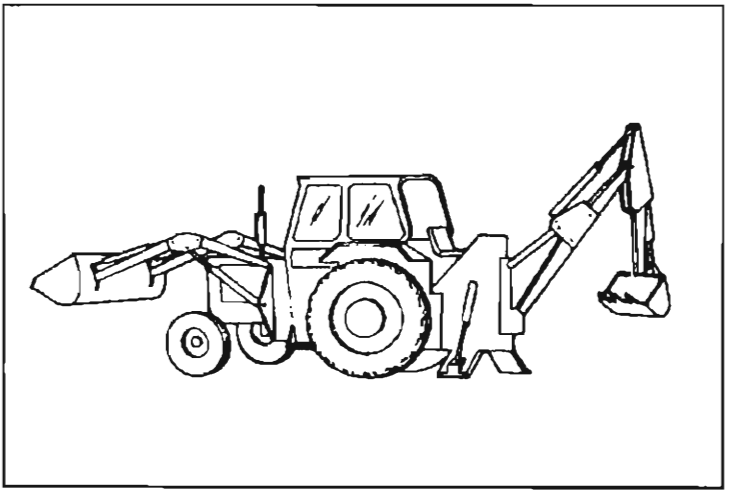
Remote cylinders (rams). Remote hydraulic cylinders can be used for tipping trailers, lifting machinery out of the ground, assisting the tractor's hydraulics, or for lifting and lowering remote draw bar hitches. The tractor's hydraulic 3 point hitch uses these rams, as do loaders and diggers.

Remote cylinder controls can be 'banked' together for excavators, front- and rear-end loaders, and attachments such as grabs and cutters.

Rear mounted diggers, ditchers, and loaders (Figure 6). Rear mounted diggers, ditchers, and loaders usually mount to the back of the tractor, and often have their own hydraulic pump driven from the tractor's PTO shaft. They use several rams to move the jointed digger arm.

Front mounted loaders (Figure 6). Front mounted loaders mount on the front of the tractor. They are usually powered from the tractor's hydraulic PTO. They use rams to move the jointed loader frame and bucket.

Figure 6. Rear mounted digger/ditcher and front mounted loader.



5 Safe operation of tractors

Safety must be the first concern in tractor operation; there can be no compromise. Agricultural equipment is dangerous, and taking chances will lead to accidents.

Accidents do not happen—they are caused

Accidents can be avoided through proper training of tractor operators and a commitment to safety by farm managers.

Training. Proper training of tractor operators is the first step towards a safe operation. Operators should read the tractor operator's manual and be trained before they are allowed to operate a tractor.

Attitude. Tractor operators must understand that safety is the most important goal. The farm manager plays an important role in determining the attitude of workers. An operator who thinks production is more important than safety may cause an accident by ignoring safety to increase production.

Controls. The operator should have the essential controls within comfortable reach when seated. These controls are the steering wheel, gear change levers, handbrake, clutch and brake pedals, PTO control, remote cylinder control, and any other controls that are required while operating the tractor.

Gauges and indicators. The gauges and indicators should be within easy view of the operator. Basic gauges show fuel level, oil pressure, and operating temperature. Large modern tractors may have additional gauges and indicators to show fuel efficiency, wheel slip, work and progress rates, and other information.

Hints for safe operation

- Read the tractor operator's manual.
- Train tractor operators.
- Use safety guards, covers, rails, and gauges.
- Consider stopping distance when pulling heavy loads, especially downhill (Figure 7).
- Maintain the tractor properly, especially the brakes.
- Do not take chances.
- Do not carry passengers. The tractor's seat is the only safe place to sit on a tractor, and passengers may fall off and be crushed by the tractor or trailing implements (Figure 8). Do not carry passengers on auxiliary implements.
- Do not operate on too steep a slope. The tractor may tip over and crush the driver (Figure 9).
- Do not disengage the clutch or the gearbox when going down a hill, especially when pulling a load. The tractor may run out of control if you do.
- Do not drive too fast. High speed may cause the tractor to overturn and injure the driver. Excess speed also places extra stress on the 3 point hydraulic hitch and may damage it.
- Do not hitch loads to the top of the 3 point hitch or above the centerline of the rear axle (Figure 10). The tractor may tip over backwards if you do, especially when towing uphill. Always use the drawbar hitch instead.
- Do not get off the tractor until it stops completely. You may be crushed under the wheels.
- Wear proper clothing and shoes or boots. Loose clothing can catch in things, slippers can 'slip'.

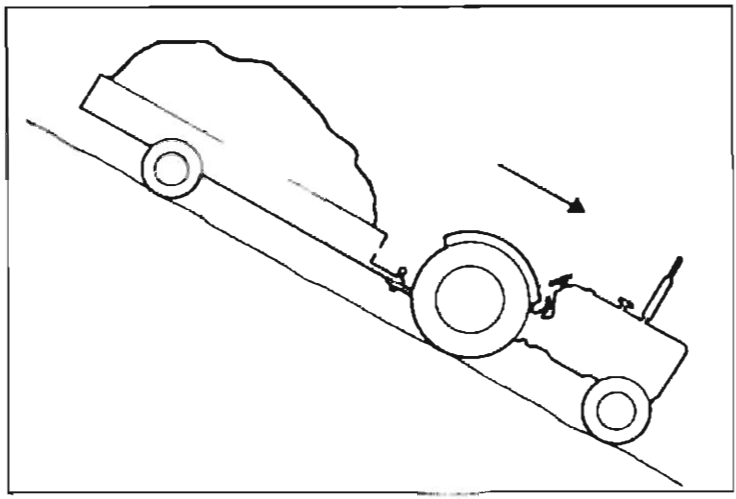
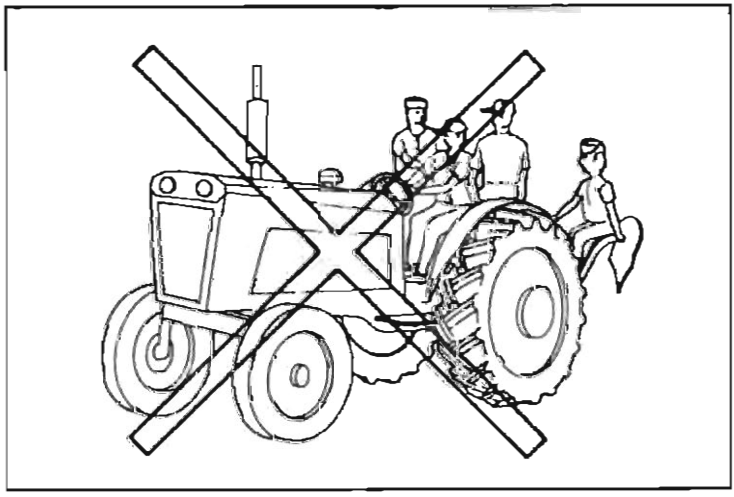


Figure 7. Consider stopping distance when pulling heavy loads, especially downhill. Never declutch.

Figure 8. Do not carry passengers.



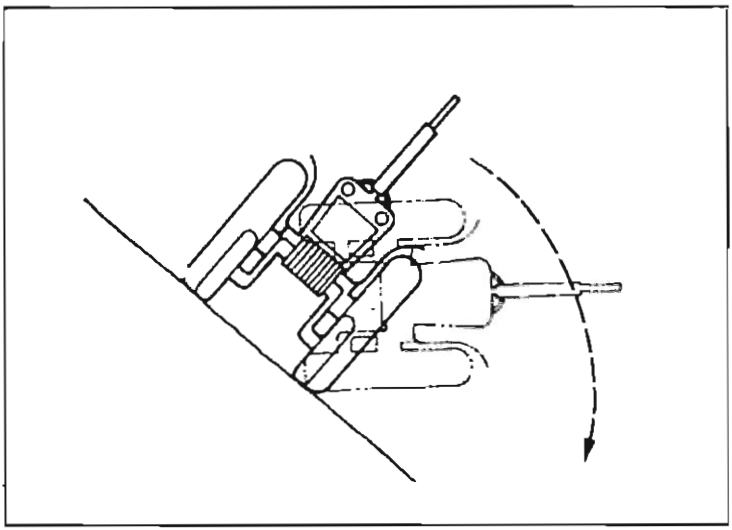
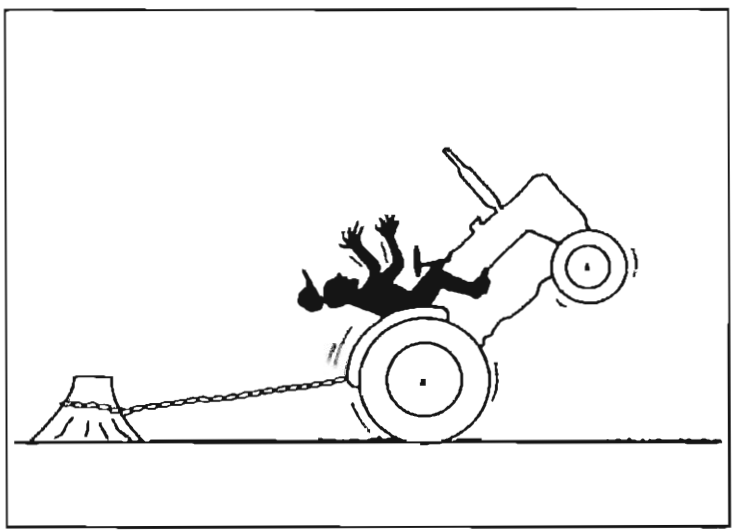


Figure 9. Do not operate on too steep a slope.

Figure 10. Do not hitch loads to the top of the 3 point hitch.



6 Maintenance

The reliability of any equipment is totally dependent upon the quality of its maintenance. If a tractor is not properly maintained, it will give bad service and may be damaged beyond cost-effective repair. Properly maintained tractors will give many years of service.

Oil and fuel. Possibly the most important aspect of maintenance is to use the correct grade of oil. Many machines have been damaged through the use of the wrong oil.

Oil has a fixed service life, of about 200 hours in an engine. After that, it loses its lubricating ability, and also becomes contaminated with soot particles and suspended metals. If oil is not replaced at this time, the engine may fail and need a costly overhaul.

Fuel should be clean and free of water. Be wary of adulterated fuel, for example, diesel mixed with kerosene. Severe engine overheating will result from preignition.

Oil and fuel filters should never be washed and refitted. Always fit new ones.

Maintenance information. The operator's manual is a good source of information for deciding what maintenance to perform and when to do it. The operator's manual shows standard maintenance procedures and intervals, states which oils to use and which alternates can be substituted, gives information on the capacity, weight, and dimensions of the machine, and provides other useful information.

Maintenance schedule. Every machine should have a maintenance schedule. Maintenance can be scheduled as daily, weekly, minor and major services, and minor or major component overhauls.

- Daily maintenance will normally be simple checks on fuel, oil and water, tire pressures, battery condition, fan belts, radiator fins for seeds or dust blockage, and any auxiliary components.

- Weekly maintenance depends on time and operating duration. It will be an extension of the daily routine, and will include greasing of some components.

- Minor services include engine servicing, and checks and adjustments on various components and operating controls.

- Major services will include engine servicing, oil and filter changes, other component changes, and checks and adjustments to controls, linkages, and drives.

- Minor or major component overhaul is necessary after several hundreds or thousands of hours of operation.

Maintenance records. Maintenance records make it possible to know the overall condition of the equipment and forecast future maintenance requirements. Records also allow you to plan for 'seasonal' maintenance. For instance, a tractor's hydraulic system must be in peak condition for plowing, but may not be needed at other times. Maintenance may be planned accordingly.

7 Bibliography

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8 Suggestions for trainers

If you use this Research Guide in training

Generally

- Distribute handouts (including this Research Guide) to trainees one or several days before your presentation, or distribute them at the end of the presentation.

- Do not distribute handouts at the beginning of a presentation, otherwise trainees will read instead of listening to you.

- Ask trainees not to take notes, but to pay full attention to the training activity. Assure them that your handouts (and this Research Guide) contain all relevant information.

- Keep your training activities practical. Reduce theory to the minimum that is necessary to understand the practical exercises.

- Use the questions on page 4 (or a selection of questions) for examinations (quizzes, periodical tests, and so on). Allow consultation of handouts and books during examinations.

- Promote interaction of trainees. Allow questions, but do not deviate from the subject.

- Respect the time allotted.

Specifically

- Discuss with trainees their experiences and problems with tractors (10 minutes).

- Present and discuss the content of this Research Guide, considering the study materials listed on page 3 (45 minutes).

  You may photocopy the illustrations of the Research Guide on transparencies for projection with an overhead projector.

- Conduct the practicals suggested on page 3 in groups (3–4 trainees per group; 1 day). Make sure that each trainee has the opportunity to practice. Have resource persons available for each group and practical.

- Organize your practicals/demonstrations well. Keep trainees busy. Prevent trainees from scattering around the field. Observe safety regulations when operating a tractor.

International Institute of Tropical Agriculture (IITA)
Institut international d'agriculture tropicale (IITA)
Instituto Internacional de Agricultura Tropical (IITA)

The International Institute of Tropical Agriculture (IITA) is an international agricultural research center in the Consultative Group on International Agricultural Research (CGIAR), which is an association of about 50 countries, international and regional organizations, and private foundations. IITA seeks to increase agricultural production in a sustainable way, in order to improve the nutritional status and well-being of people in tropical sub-Saharan Africa. To achieve this goal, IITA conducts research and training, provides information, collects and exchanges germplasm, and encourages transfer of technology, in partnership with African national agricultural research and development programs.

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