Food and Agriculture Organization of the United Nations

Training of trainers manual on the operation, maintenance and repair of farm machinery

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Preparation of this document

This training manual was prepared by Jelle Van Loon and Mayling Flores Rojas. Jelle Van Loon is an international consultant on sustainable agricultural mechanization for the Food and Agriculture Organization of the United Nations (FAO) in Timor-Leste and a mechanization specialist at the International Maize and Wheat Improvement Center (CIMMYT). Mayling Flores Rojas is an Agricultural Engineer working with FAO since 2014.

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Contents

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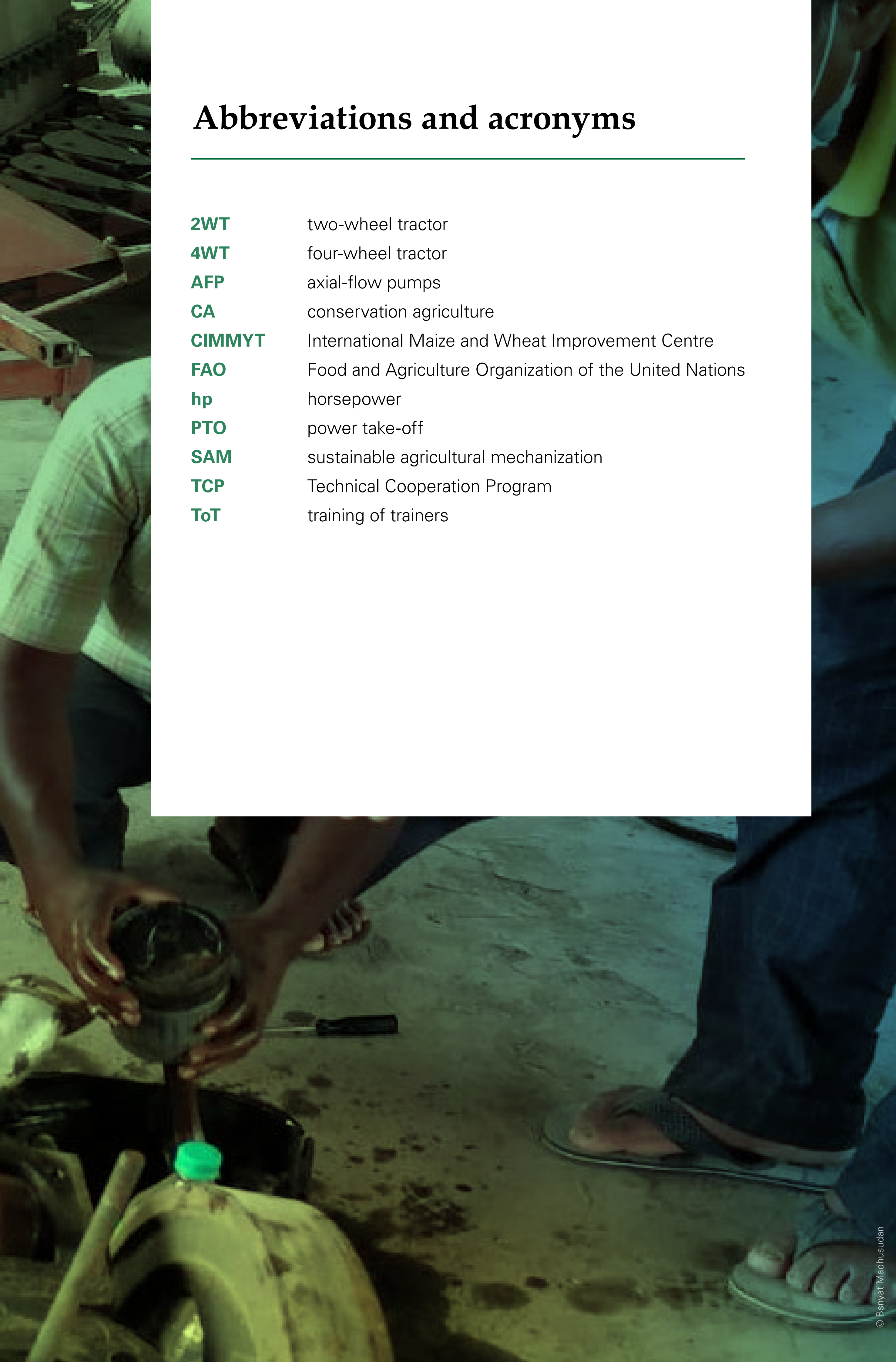
Abbreviations and acronyms

2WT	two-wheel tractor
4WT	four-wheel tractor
AFP	axial-flow pumps
CA	conservation agriculture
CIMMYT	International Maize and Wheat Improvement Centre
FAO	Food and Agriculture Organization of the United Nations
hp	horsepower
PTO	power take-off
SAM	sustainable agricultural mechanization
TCP	Technical Cooperation Program
ToT	training of trainers



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Introduction

This Training of Trainers (ToT) manual aims to provide insights into the operation, maintenance and basic repair of farm machinery. It provides an overview of the main concepts of equipment that can facilitate sustainable agriculture practices, with examples and guidelines on the topic. Its objective is to provide extension officers, technicians, mechanics, and youth with the necessary information and skills to become trainers and deliver technical capacity sessions on this topic. There is a mix of theory and practice in this training. Participants must have the time to individually perform the different tasks described in the modules with close supervision.

The training manual comprises four modules:

- **Module 1** covers different tractors as a power source and power take-off operations.
- **Module 2** focuses on the implements and equipment attached to tractors for field operations.
- **Module 3** is about harvest, post-harvest and storage technologies.
- **Module 4** covers general aspects and tips for maintenance, spare parts and replacements.

Who should use the training manual?

This ToT targets both women and men master trainers who have experience with machinery, agricultural engineering, mechanics, agronomy, machine operations, or field extension. This training is also designed to build the capacity of young, motivated and interested people who have no previous knowledge of mechanization or crop management but are eager to learn. This training can be part of vocational training programmes at the national level or as a part of an agribusiness or rural development training series.

It is advisable to have equal representation from the public and private sectors to foster rich discussion and cross-sectoral collaboration in subsequent training sessions (e.g. two participants per institution, organization, department or company). Female representation is equally important in this training; it should include women with suitable profiles to serve as master trainers as well as women with interest in mechanization to serve as female participants.

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Duration of the training course

The duration of the training varies depending on the knowledge and previous experience of the participants. In general, it is possible to deliver the full content of the training manual in 5–6 days. The trainers should select or prioritize the modules depending on the time and resources available, allowing ample time for practical exercises and hands-on experience. It is recommended to have a refresher training after the main one to reinforce the knowledge acquired and discuss possible doubts. Surveying the participants about specific content they would like to revisit or focus on may assist in planning the refresher training.

Training process

This training is a combination of theory and practical, hands-on exercises. Trainers present the content of the manual and facilitate discussions around different topics. The trainers are also responsible for preparing the field exercises and guiding participants through learning-by-doing during the practical exercises. Trainers should actively engage participants in the exercises and explain as the participants solve the matter at hand. Therefore, it helps to have two trainers working together to support each other during the execution of the training.

Preparing and organizing the training programme

When preparing the training programme, it is useful to undertake a training needs assessment to identify the topics most relevant for the participants and the right participants for the training. Based on these findings and the trainers' own experience, certain sessions in the manual can be reinforced, passed on or adapted to local conditions. Trainers need to prepare the presentation slides and handouts in advance and make sure participants have a hard copy of the training manual to follow during the presentation. It is also recommended to have more in-depth side information that the participants can refer to. Please consider translating the manual from English to the local language, if necessary, while ensuring the correct translation of technical terms.

Venue

It is encouraged to engage local vocational training centres in preparing and executing the training, as this permits building ownership in local partners and influencing their curriculum. The practical exercises require premises with equipped repair workshops and a test field area. The field location and accommodation would be ideally in the same training centre or nearby. The training room should be comfortable and big enough to accommodate the total number of participants and support working groups.

To increase women participation in the training, the training should be held at a location that is close enough to the targeted communities and at a time that does not hinder the development of their daily tasks.

Equipment and materials

For the theoretical sessions, the trainers need presentation equipment such as a display screen for the slideshow presentation or flip charts. Recommended materials for these sessions may include:

- classroom whiteboard;
- flip chart stands (sufficient for small group exercises);
- computer/laptop with projection capacity and overhead projector;
- handouts/materials in ring binders (one for each participant);
- flip chart paper and markers of various colours;
- thick marker pens of different colours;
- pens and pencils; and
- plastic tape or similar to attach the paper to the wall.

For the practical sessions, the trainers need to ensure the availability of machines and equipment covered by the training (e.g. two-wheel tractor and set implements). Similarly, the spare parts, tools and consumables (e.g. engine oil, filters, etc.) need to be available to carry out the practical exercises. The recommended list includes:

Table 1: Suggested materials for the practical training exercises

drop level metre	fuel diesel (l)
flexometre (5 m)	fuel gasoline/petrol (l)
measuring cups (small, medium, large)	fuel container
Funnel	multimetre
oil pan/recipient	V-belt spares, matching 2WT
soap and brush	metal brush
bucket (8L)	primer spray paint for metal surfaces
cleaning rags	plastic steel
Grease	hammer
Oil SAE 30 grade oil	mallet
WD-40 multipurpose spray can	chalk powder or lime
manual oil pump	50-metre measuring line
strap wrench or oil filter pliers	spray paint (white)
set of wrenches	small scale for weight

adjustable wrench (English wrench)	screwdriver set (cross and flat)
ratchet and set of sockets	Allen keys sets (standard and metric)
Ruler	welding post
oil filters, matching tractors	welding wire or electrodes
air filters, matching tractors	metal sheet (3 mm)
fuel filter, matching tractors	angle grinder
air compressor	metal cutting discs
tire valve linkage	flat Metal file
tire pressure gauge	triangular metal file
radiator fluid /coolant, matching tractors	plastic transparent bags
engine oil, matching tractors (15W40 , 15W30, …)	elastic bands

It is also encouraged to provide health and safety insurance for the training participants and have protective equipment like safety goggles and gloves for all participants during the exercises.


Khedut

Module 1

Tractor and power take-off operations

Session 1.1
Four-wheel tractors and field readiness

A. General considerations for the selection, use and operation

Horsepower, operational velocity and power revolutions

Contrary to popular belief, a tractor's engine capacity or horsepower (hp) is usually not fully representative of its usefulness on the field, and therefore should not be the only indicator to consider. Far too often, bigger tractors are chosen because they appear to do the job quickly, but this might come with a steep increase in production costs because of unnecessary fuel consumption. When setting out to mechanize a specific activity of the farm operations, it is always important to consider the frequency, intensity, speed and surface area one intends to work.

For land preparation, the size of the farmland and the type of soil will indicate the need for horsepower. For mowing, planting or fertilizer application, often there is no need for a strong engine. In this case, the mechanism taking power from the tractor to operate the attached machinery (see power take-off or PTO) and the power revolutions it produces (PTO-rpm; between 540 and 1000 rpm for medium and large tractor engine rigs, respectively) is of far greater importance. As such, lighter engine alternatives or two-wheel tractors (2WT) can be a more cost-efficient solution and should be considered before recurring immediately to four-wheel tractors (4WT). For example, residue management on a small surface area but with extended length and narrow borders might be better to work with a roller-crimper pulled by a 15 hp 2WT. Contrastingly, using an 80 hp 4WT that pulls a strip-tiller attachment to prepare a longer-term seedbed on heavy clayey soil might be exactly what is needed. In that case, make sure the attached implement is the right size and fit for the tractor's power, as too light equipment might get easily damaged and underperform, while too heavy equipment could either consume fuel excessively, damage the hydraulic system or, worse, damage the soil and/or plants in the field if used indiscriminately. Therefore, please follow all considerations described in this manual to ensure you get the best out of your tractor and farm equipment.

Finally, when purchasing a tractor, check with your provider the availability of spare parts and most common maintenance consumables like filters, oils and tools. These are essential to maintain your equipment in excellent condition throughout the years.

Connecting, centring and power take-off

Usually, fieldwork is done by attaching a specific implement to a tractor. The tractor either pulls the implement using the **three-point hitch** or powers it through connection with the **power take-off (PTO)**.

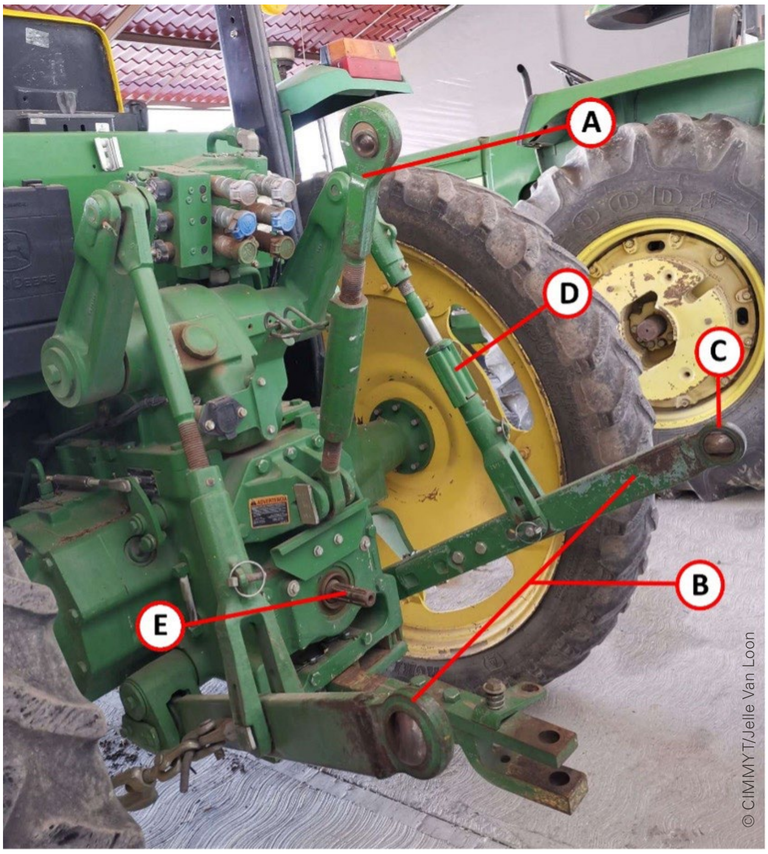


Figure 1: Overview of implement-attaching mechanism or three-point hitch on the back of a four-wheel tractor, with (**A**) upper hitch point on upper link arm, (**B**) lower point span, (**C**) lower hitch point, (**D**) lift arm, and (**E**) the power take-off or PTO.

For most farm implements, a **three-point hitch** is to be attached to a tractor. When attaching an implement, the equipment should be centred and levelled behind the tractor to ensure it follows smoothly behind the tractors gauge and has an even lift on turning. When an implement needs rotational power to operate, a flexible PTO shaft is also used to connect it with the PTO from the tractor.

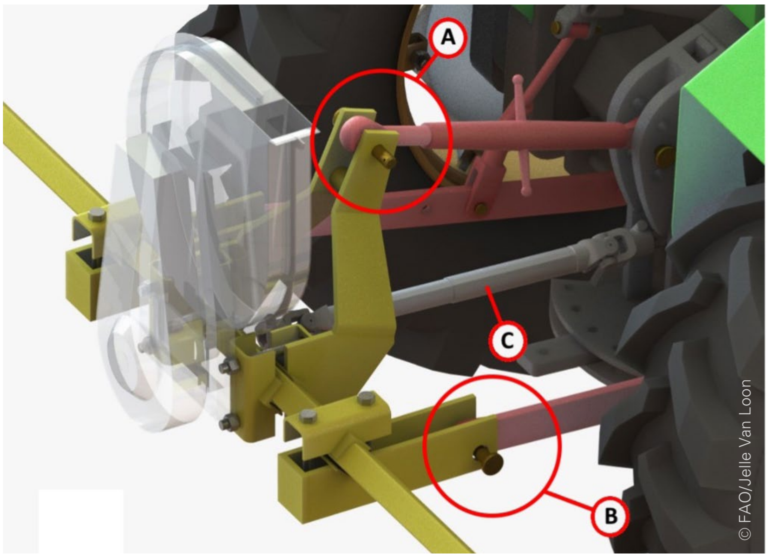


Figure 2: Connection between three-point hitch for implement (in yellow) and connection to tractor (in red), (**A**) shows the central tower connection with upper link arm, (**B**) shows the lateral hitch point connection with the tractors link arms and (**C**) shows the connection with the power-take-off and the PTO shaft.

Steps to connect implement to tractor:

1. Approach the implement with the tractor in reverse until the lower link arms are aligned with the lateral connections of the implement attachment points.
2. Connect lateral hitch point (B) with lower link arm connections and slide in the connecting rods. Make sure the rods are secured with safety pins.
3. Connect the upper link arm with the central tower of the three-point hitch (A) by sliding through another connecting rod with a safety pin.
4. Using the upper link arm from the tractor, you can move the implement closer to or further away from the tractor until the implement's inclination is levelled with the ground.
5. Finally, connect the power take-off (PTO) shaft with the power take-off outlet of the tractor.
   a. Make sure the shaft has the right length and the profile matches the tractor's PTO.
   b. If hydraulics needs to be connected, do this now, ensuring the valves click into place before activating them.

Before taking the implement out to the field, it is important to centre the implement properly to ensure uniform and correct work on the field as not to harm crops or borders. For this, one must ensure that the implement is levelled across both the width and length of the machine.

Steps to centre and level implement behind the tractor:

1. With the implement attached to the tractor, measure the length of the fixed lift arm.
2. Measure the adjustable lift arm and turn the linkage to match the length of the fixed arm.
3. With the implement attached to the tractor and hanging just above the ground, place a drop level metre on the lateral side of the implement.
4. Lift up the implement with the tractor and adjust the connection angle by turning the linkage of the upper link arm until the drop metre indicates it is level.

If the implement requires a connection to the tractor's PTO to operate, such as in the case of precision seeders or mowers, a PTO shaft should be inserted. One end of the PTO shaft connects to the PTO of the tractor, while the other end connects to the drive axle of the implement. Make sure that the implement does not require a rotational axle velocity (or revolutions per minute - rpm) that exceeds the capacity of the tractor as this might damage the transmission. In general, small to medium tractors produce 540 rpm at the PTO, while bigger tractors produce 1 000 rpm. Some tractors have the capacity to select either setting.

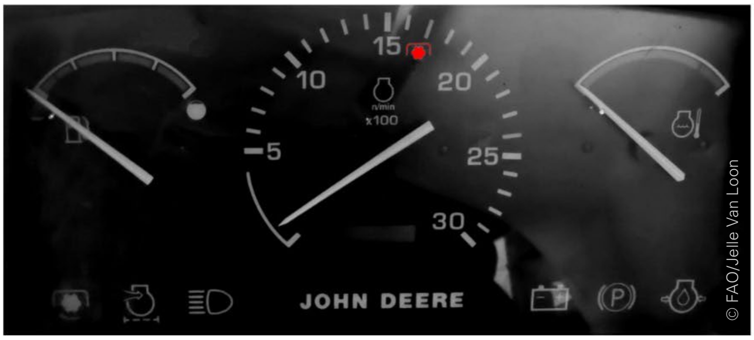


Figure 3: Standard power take-off (PTO) shaft or cardan with flexible end joints, and diagram of tractor dashboard with an indicator light that shows optimal engine RPM to use the PTO marked in red Note: Engine revolutions, which show on the dashboard of the tractor are not the same as PTO revolutions, the symbol marked in red represents the engines revolutions at which the PTO reaches its operational velocity (either 540 or 1000 rpm, depending the model). In this case, the tractor indicates that at 2000 rpm engine revolutions the PTO reaches operational speed.

Steps to insert and attach the PTO shaft:

- With the implement attached to the tractor, locate the PTO outlet on the tractor.
- Make sure the shaft has the right length and the profile matches the take-off; align the teeth of the shaft with the PTO.
- Press the safety pin and slide the shaft onto the PTO from the tractor, making sure the safety pin locks into position.
- Attach the other end of the PTO shaft with the driving axle connection of the attached implement in the same fashion.

Traction and drive train

In contrast with farm equipment taking power from the PTO, most mechanical implements work with traction generated by wheels in contact with the ground that transfer the revolving motion through the drive train to all functional moving mechanisms, as is the case for mechanically driven seed metres.

The drive train usually consists of a series of axles, sprockets and chains to ensure the operating mechanisms of the farm equipment work at the correct speed (rpm) for proper functioning. When the implement comes with its own wheels that touch the soil, these traction wheels generate the needed rpm for the operating mechanism. In this case, it is important to minimize slipping of the wheels as this will interrupt operation. Finally, these wheels can often be adjusted to aid depth control of soil-engaging components.

For all mechanical operating systems, it is essential to keep all components clean, greased up and checked frequently (preferably before the start of any field operation) to ensure the longevity of the machinery. At all times, keep clear from chains and sprockets when the tractor is in movement, as these can cause serious injury if not taken into notice.

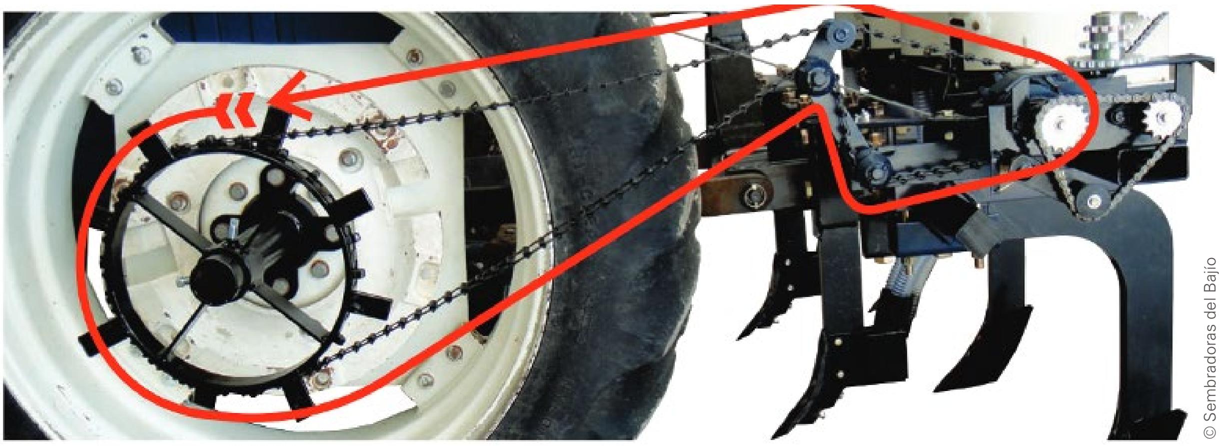


Figure 4: Drive train consisting of chains, transferring rotational movement to an attached seeder implement from the tractor's main wheel axle.

Fuel consumption and field efficiency calculations

Fuel consumption is an essential factor to consider when calculating the cost for fieldwork with tractors, and this varies when working on different soil types and performing different operations (i.e. land preparation uses more fuel than fertilizer application). A simple and straightforward method to calculate fuel consumption of a tractor with an implement attached is the "Full Tank Method".

Steps to calculate fuel consumption – FULL TANK METHOD

1. With the tractor turned off and standing on a flat surface, fill the fuel tank completely and take a visual reference point at the inner rim of the fuel tank.
2. Do the planned fieldwork and measure the time it takes to finish a specific area.
3. Park the tractor on the same flat surface as before and turn off the engine.
4. With a measuring cup, fill the fuel tank up again to the same reference point, and note the amount of fuel added to reach this point.
5. Divide the added fuel volume by the field surface area worked to calculate the fuel consumption per surface area.

$$Fuel\ consumption\ (l/ha) = \frac{\text{Added Fuel Volume } (l)}{\left(\text{Field Surface Area } (m^2) / 10\,000\right)}$$

6. Divide the volume of the fuel added by the time elapsed in seconds during fieldwork and multiply by 3 600 to calculate the fuel consumption per hour.

$$Fuel\ consumption\ \left(\frac{l}{h}\right) = \frac{\text{Added Fuel Volume (l)}}{Elapsed\ time\ on\ field\ (s)} * 3\,600$$

Once entering the field, the tractor with the attached implement can work long hours without interruption in optimal conditions. However, depending on the difficulty of the terrain and the equipment's functionality and/or overall state, the tractor may have to pause during field operations to amend problems or refill seed or fertilizer. These stops slow down the process and have to be accounted for, as they affect field capacity and performance of the equipment.

Keeping a regular track of this parametre can help signal when to review and prepare the machines for maintenance. A lower field capacity means the tractor spends more time standing still on the field when it should be moving and operating.

Steps to calculate Field Efficiency:

1. Measure total time from start to end to complete the operation on the field.
2. Measure dead time by measuring the total amount of time the tractor with attachment is NOT operating while on the field.
    a. Dead time for repair or reloading can be tracked separately if you are interested in monitoring maintenance needs or fieldwork efficiency, respectively.
3. Calculate the active time by subtracting the dead time from the total time.
4. Divide the dead time by the active time to get the field efficiency ratio.

$$Field\ Efficiency = \frac{Dead\ time_{\ Repairs}(s)}{Active\ time\ (s)}$$

5. If this number goes up over time, it is time to give the tractor and/or the attached farm implement a thorough inspection and do some maintenance.

B. Maintenance and upkeep

When using a machine continuously, especially on rough terrains, it is normal for the machinery to break down once in a while. Nonetheless, a series of simple measures can be taken to keep your equipment and implements in optimal working conditions. Besides cleaning with soapy water after use, storing in a suitable, preferably covered area protected from harsh weather conditions and performing regular inspection of critical components is essential. Additionally, greasing up where needed and checking for wear and tear can go a long way in reducing downtime of your equipment and extending its utility life.

Structural inspection

The main structure of most farm implements is built from sturdy steel and metal parts. Although they appear to withstand rough conditions, it is important to visually inspect any possible cracks or bends, including taking care of paint layers as this keeps rust and oxidation from occurring, which can deteriorate the integrity of the structure at bay. Also important is to check hardware components, like nuts and bolts, as they can get loose and lost due to the heavy vibration of the implements on the field. One has to make sure all components are properly mounted and tightened before any field activity.

Checking slacking chains and tire conditions is a must to avoid breakdowns or more serious damage to the machine. Drive train chains should be flexible enough to bend slightly with one hand and assure smooth movement, but not so much that the chains can get hooked elsewhere or bounce from the sprockets. Often, a tensioner pulley allows reducing the slack on the chain if this exceeds 20–40 mm. Similarly, the tyre should always be properly inflated to ensure sufficient traction and to avoid premature deterioration. An easy method to check the air pressure in the tyres without a measuring gauge is to count the ridges of the tyres that are in contact with the ground: only three ridges should be touching the ground simultaneously when parked. Finally, no load should be placed on the machine when not in use as this will cause tyre damage due to material fatigue.

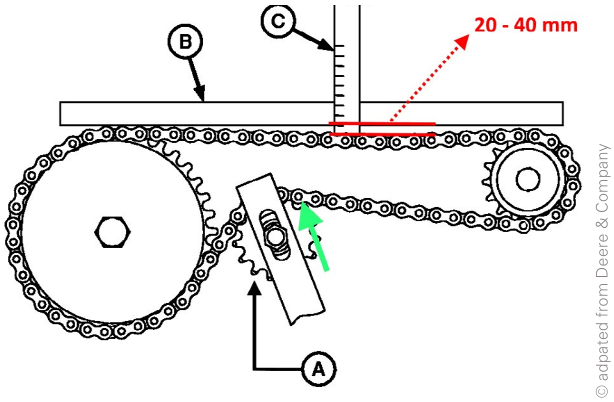


Figure 5: Diagram of checking and adjusting the tension in drive train chains using a tensioner pulley (**A**), level (**B**) and ruler (**C**) on the left, and correct tyre pressure with three tyre ridges in contact with the ground on the right.

Greasing components

The friction between moving parts of a machine cause the components to wear, ultimately resulting in failing mechanisms. To minimize the damage caused by inevitable friction, it is essential to make sure all moving parts of a machine are properly lubricated. In agricultural machinery, two kinds of lubricants are commonly used: grease and oil. **Lithium-based multipurpose grease** should be used mainly for parts with bearings or sliding mechanisms, while B.A.T. 3-type grease is preferred for bearings and pivotal connections since it can tolerate high temperatures.

Figure 6: Lubricating bearings with multipurpose grease, and a wall bearing with oil pump used for lubrication of inner components

For chains, sprockets and gearboxes, lubricating oil is the better choice as the heavier grease may clog these parts that are more exposed to dust and dirt from the field. In this case, **SAE 30 grade** oil or the more commonly **WD-40** can be applied. For fixed bearings, an oil pump should be used to regularly oil up the inner parts.

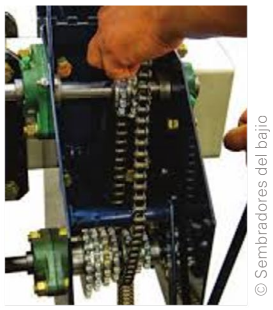
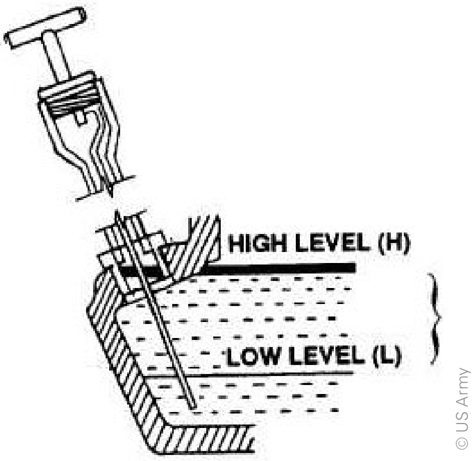


Figure 7: A dried-out chain that was wrongfully lubricated with grease instead of oil, spraying a drive chain with WD-40 for correct lubrication and calibration gearbox properly accommodated with lubricated chain.

Checking oil level and oil filter change

When using a tractor as a power source, it is wise to review oil levels before any activity. This can be done by checking the level on the oil dipstick located on the side of the tractor's engine block.



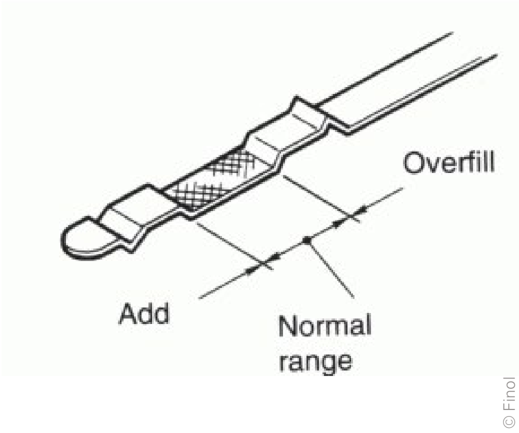


Figure 8: Diagram of the engine block with oil level indication and inserted dipstick, and oil level indicators on the end of the dipstick.

Steps to check the oil level from tractor engine:

1. Park the tractor on level terrain and shut the engine OFF for at least 45 minutes.
2. Remove the oil level dipstick, clean it and insert it again into the engine block.
3. Lift out the dipstick again and check the level between the marks on its lower tip.
4. Add oil if the level is lower than the lowest mark with engine oil as specified by the manufacturer via filler port.
5. For diesel engines, 15W40 grade oil is usually a standard safe choice.

When the oil on the dipstick has a dark colour or is filled with soot, it is time for an oil or oil filter change. Draining the oil from the engine can be done by loosening the drain plug on the bottom of the engine block. When possible, always use the oil type as specified by the manufacturers.

Figure 9: Oil drain plug at the bottom of tractor engine and oil filter canister on the side of engine block.

Steps to change the oil and oil filter:

1. Park the tractor on level terrain and turn the engine off.
2. Put an oil pan under the engine block, directly under the oil drain plug and unscrew the latter.
3. Let the oil flow out until it is completely drained.
4. Screw the drain plug back on but do not overtighten.
5. Locate the oil filter cap or canister and unscrew.
    a. This might require a special tool – Oil filter pliers or strap wrench (Figure 10).
6. Replace the oil filter with an identical new one (as specified by manufacturers).
    a. Put some clean engine oil on the rim of the new oil filter housing to seal the new oil cap as you screw it on.
7. Fill up the engine with new engine oil, as specified by the manufacturer, and check oil levels using the dipstick.

Figure 10: Oil filter pliers and strap wrench used to unscrew oil filter cap or canister to change oil and oil filter.

Additional consideration for preventive tractor maintenance

As an additional measure to keep the tractor in top condition, it is helpful to keep the air filter clean. This is done by blowing compressed air outwards to ensure the dust is removed properly rather than blown deeper into the filter. If the filter remains dirty even after air cleaning, it is best to replace this one as well. Although the air filter for the tractor engine is usually located near the radiator, its location varies but can be found encapsulated in a plastic rounded-shape or cylinder housing.

Figure 11: Cylinder-shaped air filter located in front of tractor radiator and cleaning of air filter with compressed air from inside out and at a distance.

Further, one has to make sure that the radiator fluid is always at the correct level. When finishing an activity, filling up the fuel tank is recommended, as air accelerates oxidation inside the tank, releasing rust and impurities in the fuel lines. This might cause the lines to clog and dirt to accumulate in the fuel filters. For this reason, fuel filters should also be reviewed on a timely basis. Replacement is similar to an oil filter change, but fuel filters come in all sizes and shapes, so check the manufacturers' specifications to get the correct one for replacement.

Step to change fuel filter on tractor engine:

1. Park tractor on level terrain and turn OFF, let the engine cool sufficiently.
2. Locate the fuel valve and move in CLOSE position to avoid fuel spillage.
3. Locate the fuel filter canister and unscrew.
4. Remove the old filter and replace it with a new and identical one.
5. Clean the inner housing and put the fuel canister back on while ensuring the O-rings are securely placed to avoid leakage.

Figure 12: Fuel filter and fuel valve on tractor in OFF position to replace the filter (left) and replacement of paper fuel filter after cleaning the housing and replacing the O-ring (right).

Session 1.2
Two-wheel tractors and their use

A. Models and main components

Besides the 4WT, many other power source options exist. For fieldwork on smaller plots, lighter engines mounted on two-wheeled single axle frames offer a variety of opportunities to increase productivity (without high labour requirements or complex and costly equipment). Two-wheel tractors (2WT) are also called 'hand tractors', 'walking tractors' and even 'power tillers' as they are often sold together with a rototiller implement. An overview of the main components and features is given below. Figure 13 shows two different reference models to present similarities in structure but slight differences in brand or make. The left of Figure 13 depicts an Indonesian Quick M1000 Alfa two-wheel tractor, commonly found in Timor-Leste with 8.5 hp, while the one on the right depicts a Chinese-make 15 hp model.

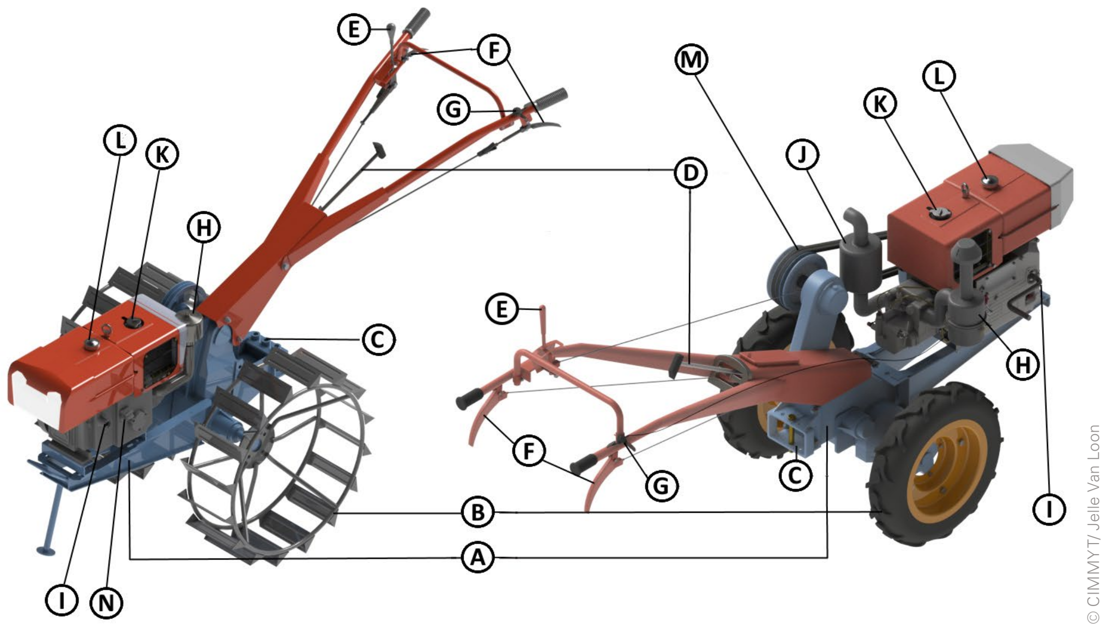


Figure 13: Overview of main components of two-wheel tractors (2WT), with a model representation of a Quick 8.5hp M1000 Alfa 2WT on the left and Dong Feng 15hp 2WT on the right.

As one can see, most components are present on both machines but in slightly different locations and forms: both engines are mounted on a sturdy frame (**A**) and have a single wheel axle with either cage wheels (**B–left**) mounted for puddled fields, or agricultural tires (**B–right**) for work in drier conditions. The frame ends in a hitch point (**C**) to attach equipment, which in some models is detachable to access a hidden power take-off directly connecting to the transmission's gears. Slightly above the transmission, the gear shift lever (**D**) is located, and two arms extend to the operators' handlebars, including the main clutch (**E**), steering levers (**F**) and accelerator (**G**). On the engine block, the main features are the air filter (**H**), the crank starter plug (I, with a crank handle on the right), the exhaust pipe (**J**), the radiator cap (**K**) and the fuel cap (**L**). Finally, transmission belts and pulley system (**M**) are shown on the Chinese model on the right, while the oil level dipstick is shown on the Indonesian model on the left (**N**).

Many similar models exist, but all have the same basic features. While both models are diesel engines, petrol engines ranging around 4–9 hp are also used as smaller two-wheel tractors. Being petrol engines, they are lighter and cheaper, which enables these two-wheel tractors to be more flexible and manoeuvrable, ideal for hilly terrains or intercropping. Once again, most parts and components are very similar, including available accessories. The choice between either depends on the user's needs and local context. For example, it can be easier with less strength to operate a two-wheel tractor with petrol engines as they are lighter. The same is true for terrains with narrow terraces, as a two-wheel tractor with a petrol engine is easier to move around.

A © Coresa; B © Quick 2019a; C © Tokopedia; D © Quick 2019b

Figure 14: A set of different petrol 2WT or hand tractors with variable configurations, with (A) a 9hp BCS power tiller, (B) Quick Cakar Baja 6.5hp cultivator, (C) a 7hp Yasuka YPT-100, and (D) a 6.5hp Quick Capung Metal paddy tractor.

Difference between petrol and diesel engines:

- Compared to petrol engines, diesel engines are more fuel-efficient but are also more prone to break down. This occurs because petrol engines solely rely on the spark plug to ignite the fuel mixture in the engine on the power stroke, while diesel engines ignite the mixture through compression.
- This means that more pressure builds up inside diesel engines, and if the engine is not kept in top condition, problems can quickly arise. Oddly enough, repairs are also often more expensive, even though the engine consists of fewer parts, making it more likely that large engine parts or the whole engine need replacement when broken.
- On the other hand, diesel engines are more efficient and produce more torque, making them more powerful, especially for towing and hitching equipment. This, however, puts an additional strain on the engine.

B. General considerations for operation

Implement hitching (trailers and ancillaries)

Two-wheel tractors (2WT) are an ideal power source that can provide sufficient traction to mechanize a diverse set of tasks on and off the field due to the wide variety of attachable implements. The hitch point of most two-wheel tractors consists of a sliding pin mechanism that can be found at the backside of the engine mounting frame and below the handlebar support (Figure 15). Depending on the model and brand, this can differ slightly. For example, some models allow the user to remove the hitch point to enable direct access to the engine transmission gearbox and use it as a power take-off (Figure 15). If this power take-off is used and transmission oil is leaked, make sure to fill this up after sealing the latch again by adding **80W 90**-type oil to the transmission block.

Most implements are hitched straight behind the 2WT. This is done by sliding a heavy pin down through the centre opening of the hitch point and subsequently aligning the hole of the implement connection in the hitch. Once aligned, the heavy pin can be passed through entirely to the bottom part of the hitch point (Figure 16). This will lock the implement in position but allow its lateral movement, offering improved flexibility during operation, especially when turning. For some specific implements, you may wish to connect it at an alternate position behind the 2WT, depending on the topologic arrangement of the crops and the type of operation performed. This might be the case for mechanical weeders, where one wants the implement **NOT** to move in the centre of the tractor (where crops are grown). In such case, the implement should be hitched using the left or right hitch point connections to avoid damaging the plant row.

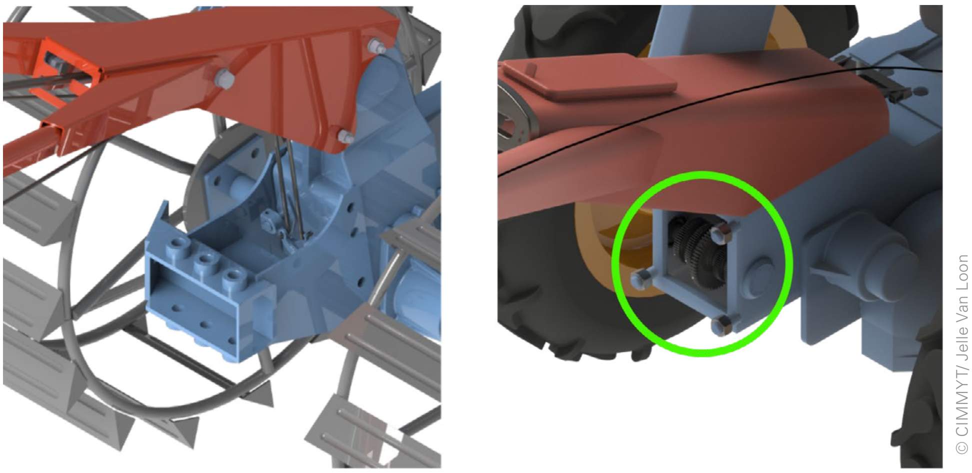


Figure 15: Hitch point of a 2WT with pin connector hole for implement attachment (left), and transmission gearbox behind hitch point in for power take-off available in some models (right)

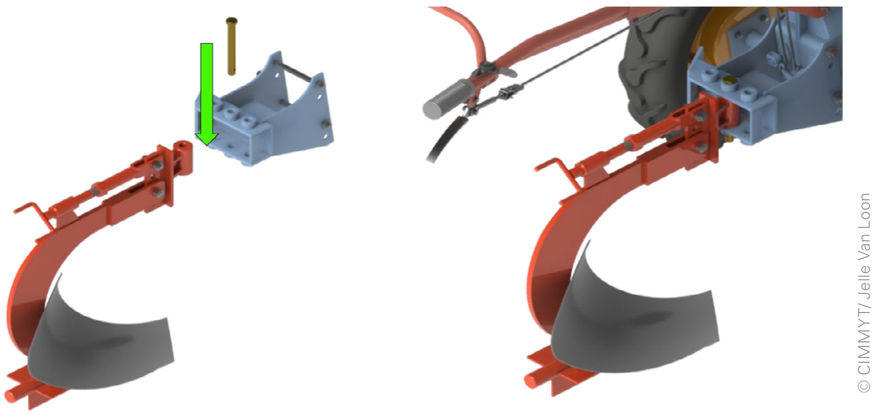


Figure 16: Diagram to insert connector pin in hitch point by aligned holes with moldboard plow implement (left), and fully attached and secured ensemble (right)

Further, when the 2WT is operated with an attachment, the operating speed should be monitored. Similarly, when trailing a farm implement on the field and, more so, on the road, one always has to ensure enough room for manoeuvring and turning. Operating a 2WT on the field should never be faster than walking speed. Turns should be made ample enough to ensure the implement follows smoothly behind. Because the hitch connection moves freely in lateral direction, making turns too tight might obstruct the operator behind the tractor, causing accidents or damage to the crop or equipment. This is because the attachment arm becomes overly stressed and can jam the whole ensemble in its movement (Figure 17). It is most important to consider this when going in reverse, as movement will be inversed and very sensitive on turns (Figure 18).

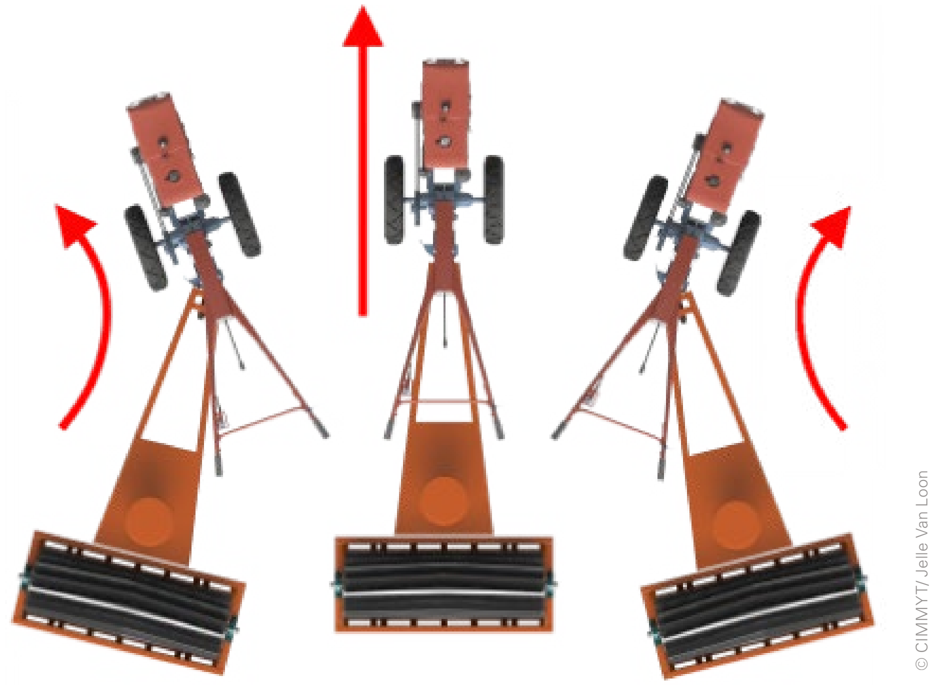


Figure 17: Movement and angle of attachment or trailing implements when manoeuvring with a 2WT.

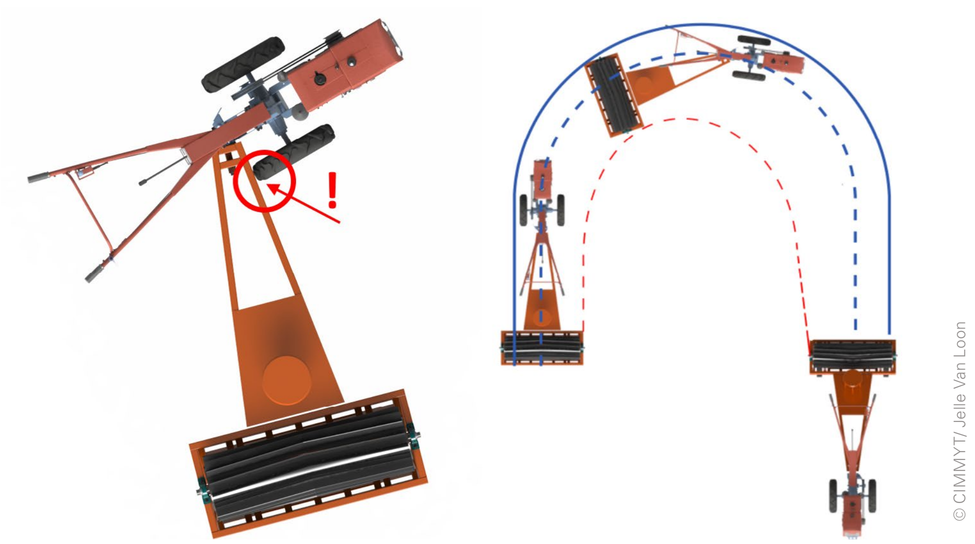


Figure 18: The danger of overturning with a 2WT and a trailing implement attached (left), and asymmetric wheel paths on short U-turns.

Engine start-up and gearbox

Some 2WT models with an electric system and "turn-the-key" starter exist nowadays, but cranking the engine is the more common and fail-safe starting procedure for walking tractors. This means turning the engine over manually using an external handle or lever to fill the engine's combustion chamber and ignite the mixture inside. To manually start the engine, the crank handle should be inserted in the crank plug located on the side of the engine block, as shown in Figure 19. Out of precaution, one should always make sure to locate all parts and check the manual before manually starting the engine, as this procedure might vary slightly depending on the model and make of the tractor, as well as the shape and location of specific components.

The gearbox and quantity of gears available also depend on the model of the 2WT, with some having only one forward speed while others having up to six speeds and one reverse available. In the latter case, it is important to notice how to change to a certain operating speed. NOTE that low gears (one through three) usually are reserved for fieldwork, while high gears (four to six) are mainly for road transportation (Figure 20).

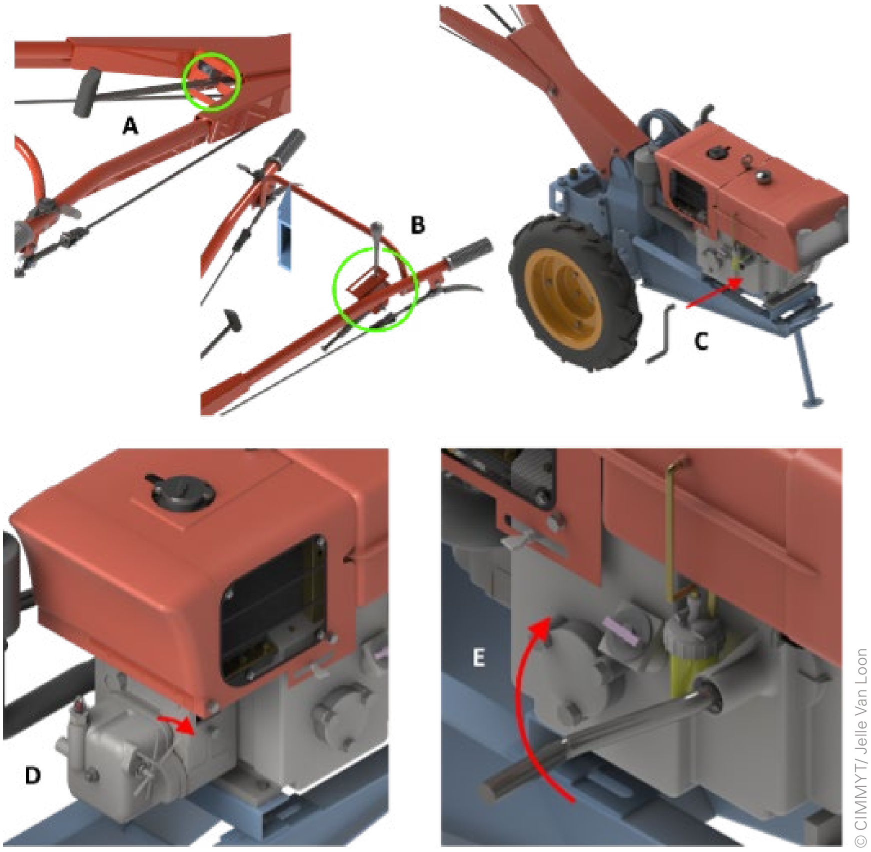


Figure 19: Steps to crank up a 2WT engine: with gear shift stick in neutral (**A**) and clutch disengaged (**B**), inserting the crank handle in engine block (**C**), pushing down the air decompression lever (**D**) and manually turning over the engine (**E**).

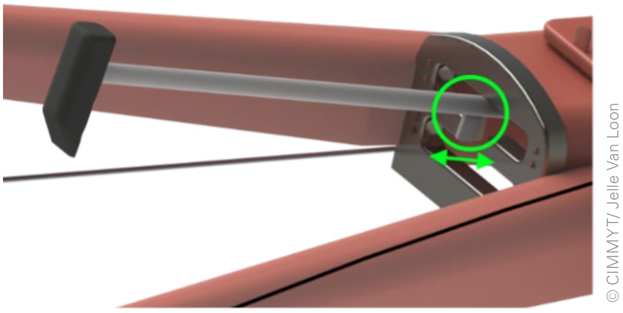


Figure 20: Gearbox representation with gear shift in high gear set position (tongue lifted out of the gearbox), ready to engage. For selecting low gears, the gear shift should be pushed until the tongue is in an inserted position.

Steps to manually start the engine using the crank:

1. Park the tractor on a level and steady terrain.
2. Make sure the clutch lever is disengaged and in full stop position.
3. Make sure the gear shift lever is in neutral position.
4. The accelerator lever should be in a half-open or start position.
5. Position the crank handle into the crank plug.
6. Press the air decompression level to release air from the engine's compression chamber when manual turnover is initiated.
7. Start turning the crank handle to the right to turn over the engine and continue with a smooth and slightly accelerated rotation until the flywheel reaches momentum.
8. Release the air compression lever while simultaneously disengaging the crank handlebar from the engine block.
9. If nothing happens and the flywheel comes to a halt, repeat steps 5 to 8.
10. As the engine starts, turn down the accelerator to a calm idling revolving engine speed.

For petrol engines, this starting procedure is a related but simpler process as it only requires the right switches to be turned for the spark plug to ignite the engine. Nonetheless, because the fuel mixture is more difficult to ignite in a cold engine, petrol engines use a "choke" function to start, where the flow of air into the mixture is constricted, thereby entering at a high pressure that causes the fuel to vaporize better (venturi effect) and subsequently ignite faster.

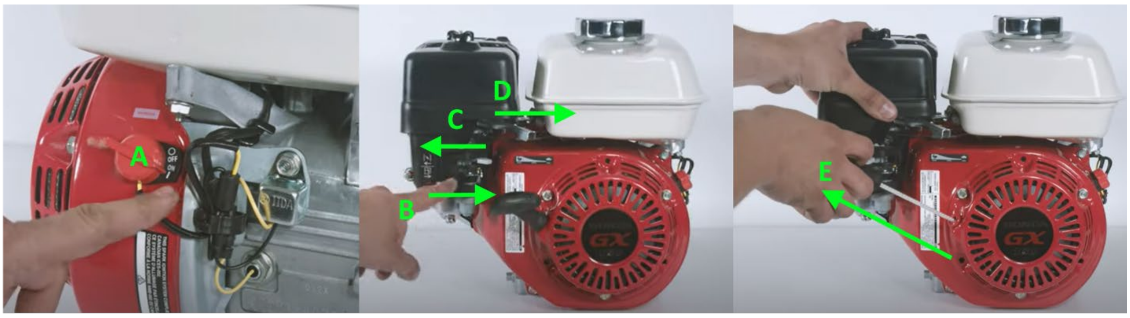


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Figure 21: Starting a 2WT petrol engine, by turning on the switch button (A), opening fuel (B), closing the choke (C) and opening throttle (D), ready to crank start by pulling the ignition cord (E).

Steps to start a small petrol engine manually:

1. Turn engine power switch in the ON position (A).
2. Turn on the fuel valve to the right in ON position (B).
3. Choke the air lines by sliding choke lever to the left (C).
4. Slide throttle lever to the right idle position often indicated with the symbol of a turtle (D).
5. Pull the recoil handle, and repeat until the engine starts (E).
6. When the engine is running, slide the choke lever back to the right and adjust the throttle to the desired revolutions.

Finally, some 2WT models recently come equipped with a battery for electric starting. If this is the case, a 12V battery pack will be visible with a key ignition system. When handled properly, this system is safe and easier. However, caution must always be made around batteries as they can spill corrosive acid when mistreated. When the 2WT is not used and stored, make sure the breaker switch is in OFF position to avoid premature battery drainage.

Steps to electrically start the 2WT engine, with key ignition switch and battery:

1. Place the gear shift lever in neutral position.
2. Make sure the breaker switch under the battery box is in ON position.
3. Introduce the key in the ignition switch and turn it to the right to turn over the engine.
4. Let go of the key the instant the engine starts up and takes over.
5. Make sure the battery is charging during operation by checking if the amperage metre on the dashboard is always in the green zone.

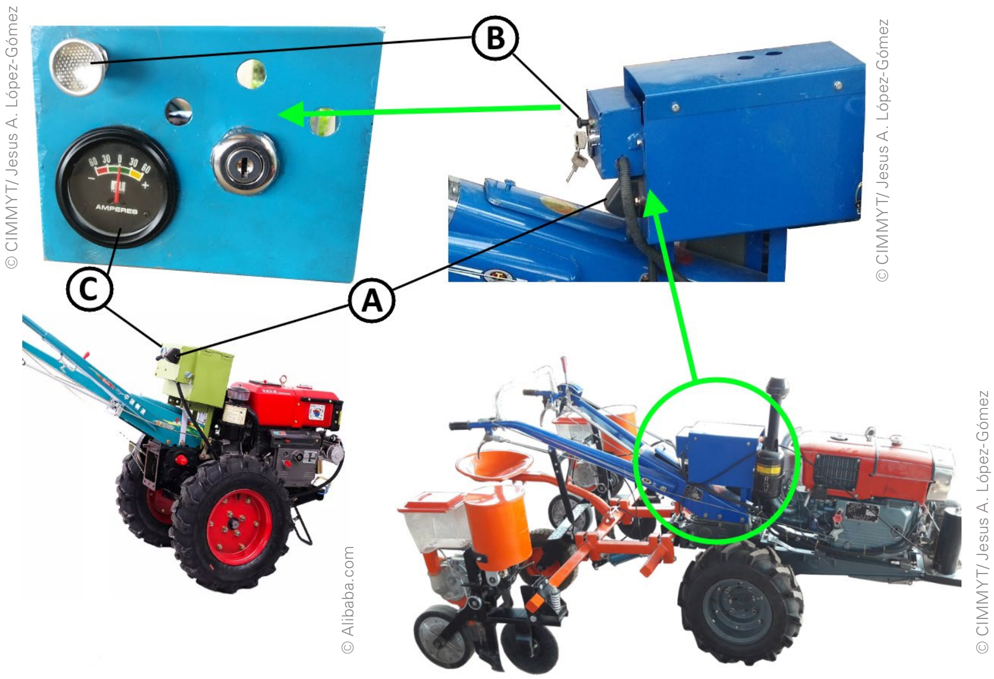

Figure 22: Starting a 2WT petrol engine, by turning on the switch button (**A**), opening fuel (**B**), closing the choke (**C**) and opening throttle (**D**), ready to crank start by pulling the ignition cord (**E**).

Power take-off and v-belt connection

The power from the 2WT is generated by the flywheel on the left side of the engine block. This flywheel is connected with two belts to a pulley that transmit the generated power from the engine to the transmission system, making the tractor's wheel axle move, when put into gear. In some models, a gearbox is accessible from behind the hitch point to connect the implement with a PTO-like mechanism, such is the case for many rotovator-tiller implements, which turn tiller blades into the soil. Before connecting an implement like this, make sure the PTO connection actually fits the 2WT PTO gearbox first. If these parts do not match, do NOT force it; the implement was designed to operate with a different model. To avoid problems here, always make sure to buy implements that match the 2WT model you have available.

For seeders or fertilizers, an alternative power-take-off is often used by placing a split-sprocket directly on the tractor wheel axle, enabling a drive train towards the implement using a chain and couples the tractor with the equipment. By removing a wheel from the axle, a regular sprocket can also be used with different sizes to control and calibrate the rotational velocity of the implement (Figure 23 - left). In some cases, however, the equipment is directly powered by the traction generated from a depth control wheel of the implement itself that turns through ground movement as the 2WT advances.

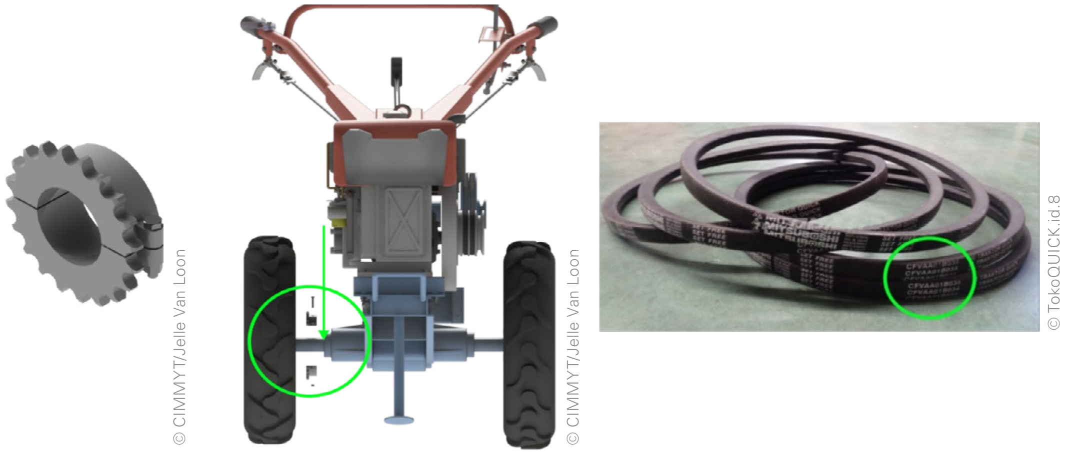

Figure 23: Split sprocket to enable traction from wheel axle of 2WT (left), and v-shaped belt with part number for power transmission

Finally, and most importantly for stationary implements like shellers or pump sets, one of the belts that connect the flywheel with the transmission pulley can be used directly to power the machine (Figure 24), with an extra belt slot often available. This way, the engine can provide power to the attached equipment with the gear shift disengaged and the 2WT standing still as if the engine is idling in neutral. When doing so, at all times, be aware of these belts when operating the equipment, and, if provided, make sure to put any protective casing back on before the work is started. The belts are called v-belts because of the v-shaped profile that makes them fit snugly in the pulley when tensioned. When replacing a broken or lost belt, make sure to look for the belt number to find a matching spare part (Figure 23 - right).

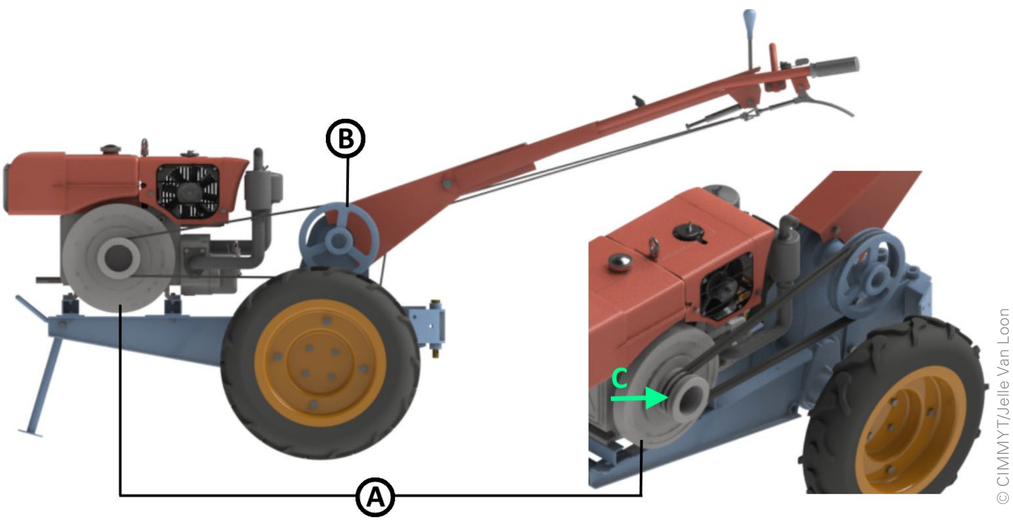

Figure 24: Flywheel (A) and transmission pulley (B) with belts (C) that allow power take-off for stationary implements

Steps to connect 2WT belt to implements:

1. Make sure the 2WT engine is turned OFF.
2. Take off one of the belts that connect the flywheel with the transmission pulley.
3. Use a stick or tube as a lever to unhinge the belt.
   a. If the belt is too tight around the pulley, you can unscrew the bolts that mount the engine block to the frame and shimmy the engine to the back to loosen the tension on the belts.
4. Place the released belt onto the pulley from the attached equipment and back on the flywheel back in the opposite direction.
   a. In case an extra slot is available to place a new belt, avoid steps 2 and 3 (C – Figure 24).
5. Position all three components in such fashion that:
   a. the distance between implement-engine and engine-transmission pulley provide sufficient tension to the belts on either side to avoid slippage or loosening;
   b. the connection is not excessively tightened as not to strain the belt and cause damage; and
   c. the belts are perfectly aligned.
6. If loosened, tighten the engine mounting screws before starting the 2WT engine.

Wheelsets and adjusting wheel gauge for fieldwork

A great advantage of 2WT over the bigger and heavier 4WT is that the former can access a broader range of field types, like paddy fields and sloped terrains, with greater ease due to their lighter weight, high manoeuvrability and low and evenly balanced centre of gravity. Nonetheless, many terrains would become nearly impossible to drive on without the appropriate wheelsets and would mean heavy work for the operator. Therefore, it is important to consider which wheels to use for each activity and field condition. A selection of different wheels sets is provided in Figure 25, although a wide range of other options and combinations exist, and each have their specific use.

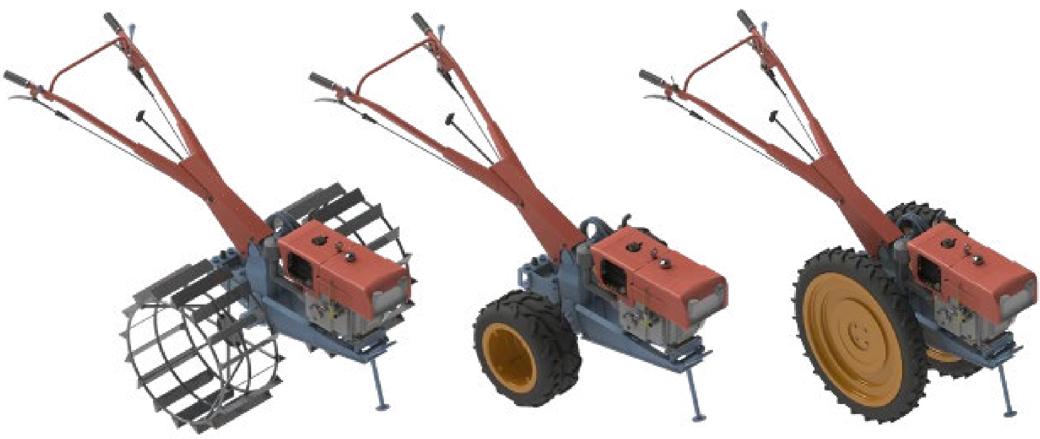

Figure 25: Different wheelsets on 2WT, with long wheel cage for deep paddy fields (left), double tires for extra traction in muddy and sloped terrain (centre), and high tires with cultivation purposes (right)

The width of the wheel base for the 2WT can also affect the mobility of the walking tractor on a field, especially after planting season has passed and crops are growing. Wheel gauges or the width of the wheel base (distance between wheels on the single axle of the 2WT) depends on the model of the 2WT, but can usually be adjusted within a certain range. For the bigger diesel engine 2WTs this distance can be set from 75 to 90 cm, by sliding the rims tightly to or away from the mounting frame (Figure 26). This feature enables using the wheel gauge of the tractor as a visual guide to ensure correct interrow distances between plant lines or facilitating passage between narrowing plant rows during the growing season for fertilizer application, mechanical weeding activities or even raised bed planting. For some of the smaller petrol 2WTs, the wheel gauge can be reduced further (20–60 cm), facilitating the use of the power source for intercropping purposes. In some cases, the wheel axle can be directly interchanged with an axle with jagged shaped knives that function as rototillers (Figure 27).

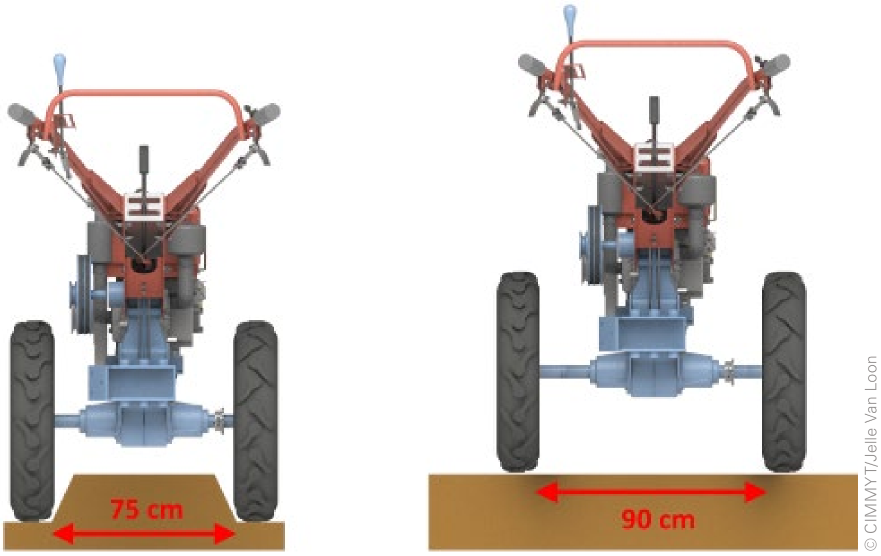

Figure 26: Wheel gauge settings on 2WT for different plant configurations, with (left) narrow bed planting and (right) flat terrain with low plant density planting

Figure 27: Small petrol 2WT with the standard farm tires (left) and a similar machine with tires replaced with blade rollers for tillage

C. Driving and general maintenance

Going out to the field

Before setting out to perform a field operation with your 2WT, it is important to take a few minutes to review that everything is in order and preventively avoid breakdowns. For this, locate the main components on the engine block in Figure 28: (**A**) air filter assembly, (**B**) exhaust – **warning**, can be hot after work, (**C**) coolant cap, (**D**) fuel cap, (**E**) oil dipstick, (**F**) fuel filter assembly, (**G**) crank plug and oil drain plug (**H**).

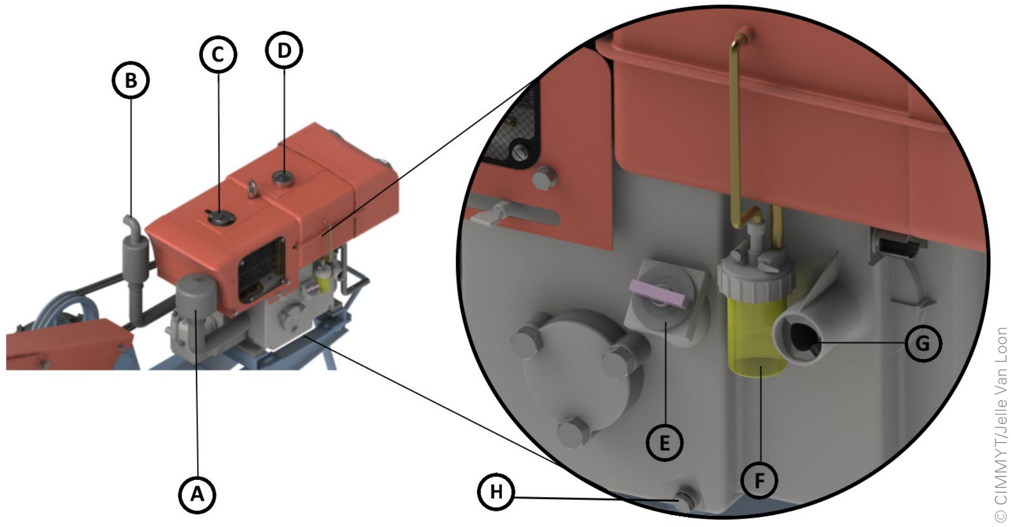

Figure 28: Two-wheel tractor engine components and important features for maintenance

Checklist before fieldwork (adapted from Getnet *et al.* [2019]):

- ☐ Place 2WT on level ground
- ☐ Check coolant level and refill with appropriate radiator coolant
    - a. Unscrew coolant cap (C) and fill up to a visual reference line or as indicated by the manufacturer
    - b. Put coolant cap back into place
- ☐ Check for sufficient fuel in the fuel tank
    - a. Unscrew fuel cap and top up the fuel tank (D)
    - b. Never start the engine with low fuel levels, as this will force air into the fuel system, and this will cause the engine to stall.
    - c. A strainer or mesh can be placed in the fuel fill hole to prevent dirt from entering the fuel tank
    - d. Screw on the tank cap again and clean all accidentally spilled fuel before starting up the engine.
- ☐ Check for the oil level in the engine
    - a. Unscrew the dipstick (E) and remove it from engine block.
    - b. Clean dipstick, reinsert and lift out again.
    - c. Check for oil level by using the marks on the dipstick and check oil colour.
        - i. If the level is low, add some extra oil
        - ii. If colour is very dark and fluid is not transparent, it is time for an oil change
    - b. If adding oil, do so preferably with the type specified by the manufacturer. For most petrol engines, 15W30 can be used, while for diesel engines, 15W40 can be used.
    - c. Do not overfill and reinsert dipstick when finished
- ☐ Check tyre pressure
    - a. For small tires, two tire ridges in contact with the ground should be fine
    - b. For large tires and with heavier implements, three ridges should do
- ☐ Check the tension of the belts and make sure engine bolts are tightened on the mounting frame.
- ☐ If an implement is to be used, make sure it is properly hitched and secured.

Driving a two-wheel tractor

With everything checked and in order, the 2WT (and implement) is ready to be moved to the field and start working. Start the engine manually with the crank or electric starter as described earlier.

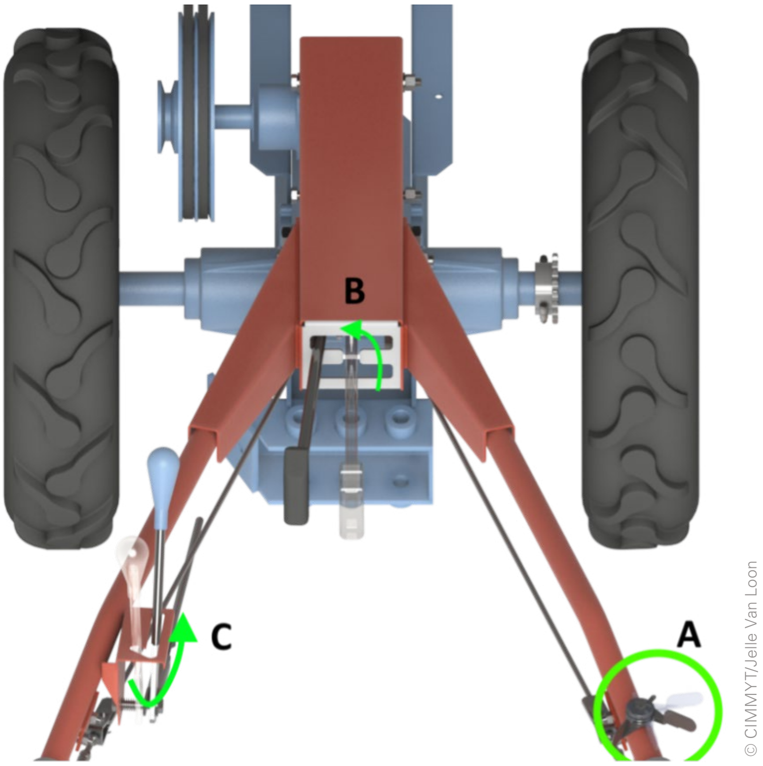

Figure 29: Handle bars components and actions to set 2WT in operation, with (**A**) accelerator and throttle positions, (**B**) shifting gear stick in first gear, and (**C**) engaging the clutch

Steps to start driving your 2WT:

1. Make sure the fuel lines are open by moving the fuel valve in OPEN position.
2. Position yourself at the back of the 2WT, right behind the handlebars.
3. Position the accelerator is an intermediate position, a bit above ¼ of full throttle (A).
4. With the engine idling, place the gear shift into the first velocity or forward speed position (B).
    a. It is important to follow the indications on the gearbox, as this varies for different models.
    b. Some gear shifts have double positions – one in slow and another in high speed. Make sure you start at a slow speed to begin.
5. Slowly change the position of the clutch lever into forward/engaged position (C).
6. Be ready to increase the throttle slightly if the engine appears to be stalling
7. **Be alert!** The tractor will start to move forward now.
8. To switch to second gear, disengage clutch lever while moving the gearshift stick into velocity 2. Slowly engage the clutch again, but be ready for a more sudden and brusque movement forward of the 2WT.

Cleaning and changing filters for oil, air and fuel

The air intake of all engines is protected with an air filter to avoid dust and dirt getting into the engine. The air filters' purpose is to trap this dust and therefore should be cleaned regularly. For both petrol and diesel 2WT this process is quite similar, where the air filter is located in a special housing.

The air filter can be reached by unscrewing the wingnuts (**A**) on top of the housing (**B**) and sometimes another one on the filter itself. Once the housing is removed, the air filter becomes exposed. Make sure you keep track of, and always put back, any rubber O-rings (**F**) or gaskets (**E**), since these are essential to avoid air entering through the joints, and when not present, the air filter loses its purpose. In diesel engine (left), make sure the reservoir (**D**) contains sufficient oil, while for petrol engine (right) the foamy cover (**H**) should be humid or sticky with oil, as this is the first barrier against dust getting into the system by which the oil makes the incoming dust stick. In this sense, a dried-out air filter will absorb fewer particles from the air. Next, clean the foamy cover of the housing with gasoline if found with accumulated dirt. Replace the paper filter, or if the inside is accessible, clean it using compressed air. Always blow air from a distance, as applying the air too close will break the fibre structure of the paper films inside. When done, assemble all parts in reverse order back onto the engine mount (**G**).

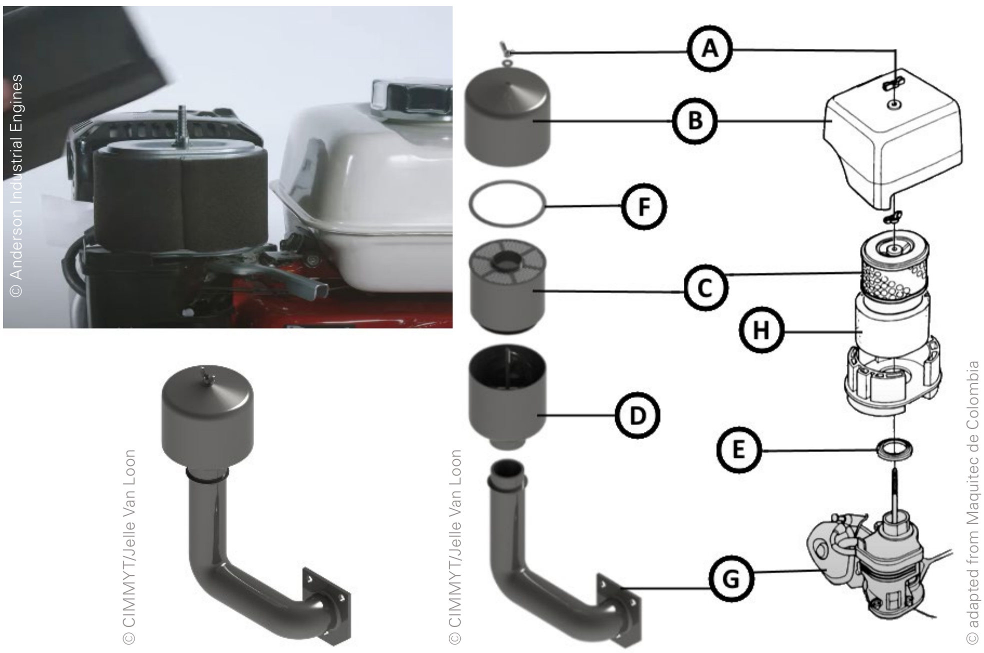

Figure 30: Air filter location in petrol engines (upper left) and diesel 2WT engines (lower lever), and parts with (**A**) wingnuts, (**B**) exterior housing, (**C**) air filter, (**D**) interior housing, (**E**) oil gasket and (**F**) O-ring, (**G**) engine mounting structure and (**H**) foam cover.

For oil filters and oil change, the same procedure as described for the 4WT can be followed, although many 2WT do not have an oil filter. However, when the oil on the dipstick is dark and non-transparent, it is time for an oil change. Locate the oil drain plug on the bottom or lower edge of the engine block and unscrew without applying too much force. Let the tank drain completely, tighten the screw manually and fill up the engine block once more. Some 2WTs present an oil pressure gauge that changes colour when the engine is running to indicate the lubrication system is pressurized.

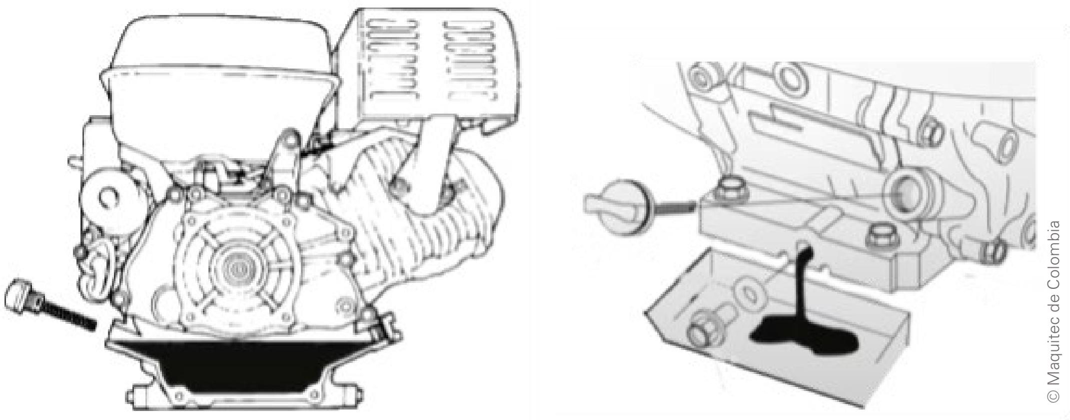

Figure 31: Petrol engine and dipstick to check oil levels (left), and oil drain plug location (right)

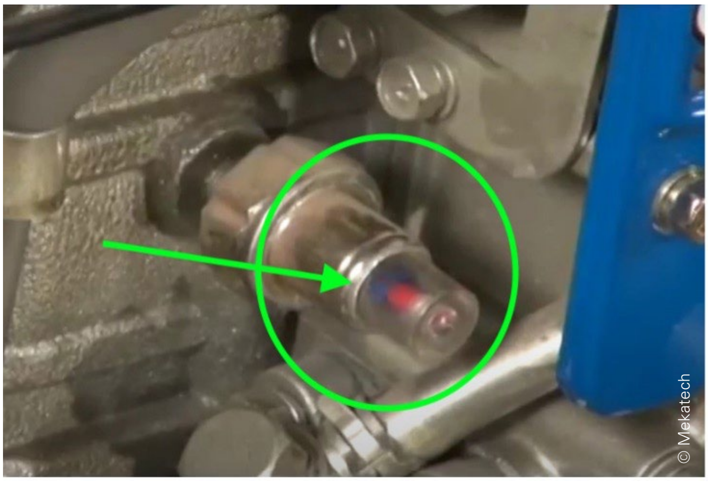

Figure 32: Oil pressure indicator on the side of some 2WT engine block, to indicate correct engine pressurization by changing from red to blue color with engine starts running.

Fuel filters are also located on the lateral side of the engine block and can be changed as described for the 4WT. If the filter appears dirty and shows damage, replace it with a new one and handle it with care when installing. If the filter does not show any damage, rinsing with clean fuel is enough, and it is recommended to do so every 100 hours of work. Make sure the fuel lines are closed before unscrewing the fuel filter. In most models, the fuel valve is located just above the fuel filter. If air comes into the fuel lines during this process, the fuel system has to be purged. This can be done by loosening (not unscrewing!) the fuel purge nut (located near the fuel injection pump), which can be found by following the fuel line from the fuel filter.

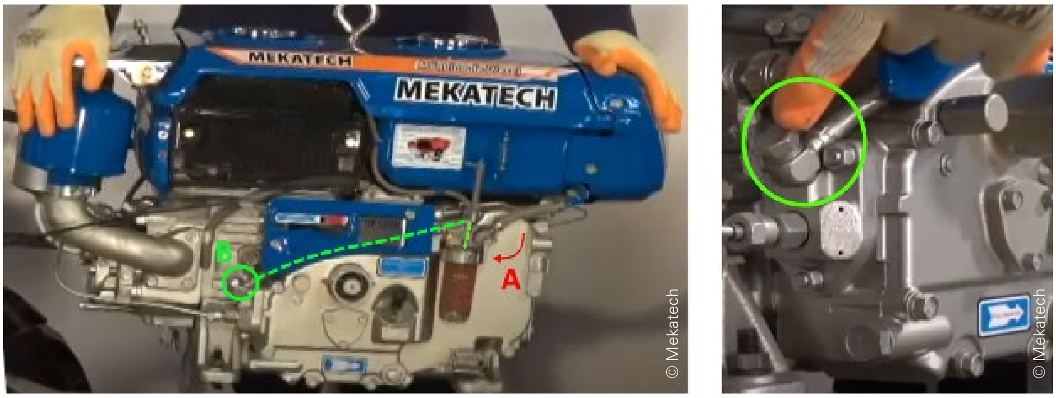

Figure 33: Fuel filter and fuel lines to fuel purge nut, with (A) fuel line valve right above fuel filter canister, and (B) fuel purge nut to release air from lines if loosened.

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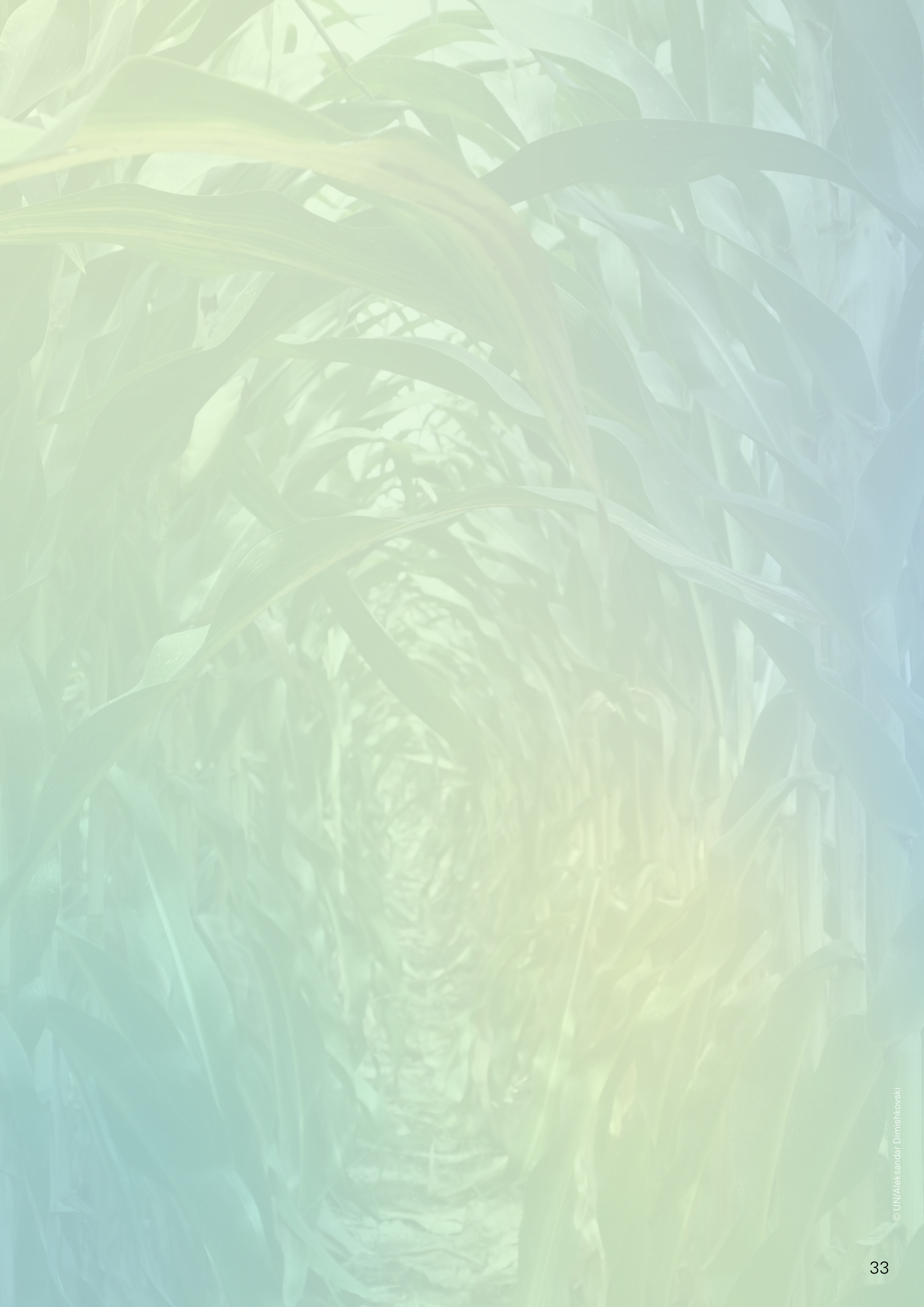

Module 2

Implements and equipment attached to tractors and field operation

Session 2.1
Field operations during the cropping cycle

To grow crops and produce food, a series of field operations with different levels of labour and time requirements have to be undertaken throughout the year. As discussed in Module 1, tractors are merely mobile power sources that offer pulling strength or a rotating power take-off to perform certain field operations. Hence, it is the equipment attached to the tractor – or implement – that performs the task at hand. This module gives an overview of equipment used for different field operations during the cropping cycle.

There is a wide variety of commercially available machines and equipment. To select the correct one for a specific operation, one must account for:

- which crop is being grown;
- which field operation is to be performed;
- the plot size;
- the soil condition in terms of texture and moisture level;
- the landscape; and
- time availability; etc.

Indeed, not all equipment is suitable for working in heavy/clayey soils or on sloped terrains, and some tasks are more time-sensitive than others. Methods that enable sustainable use of the available land while increasing productivity should be considered, especially in the context of good farming practices. These practices build on sustainable principles, where correct management of farm inputs results in a profitably stable and environmentally sound production method. A few examples include reduced tillage operations to minimize soil disturbance, direct seeding with crop residues retained on the topsoil, and establishing a diversified crop rotation scheme that maintains a healthy soil structure and nutrient content. For post-harvest operations, it is important to consider the production volume (e.g. tonnes of rice to thresh). The selection of the machine and equipment will depend on the user too. For example, if women are to operate the machine, one must consider women's needs and preferences.

Planning ahead and chronologically writing down the various field activities before the growing season starts is integral. It helps to visualize these activities throughout the year and establish a reference baseline to select the suitable machine for each field operation. This timeline helps to keep track of required tasks and makes it easy to identify critical times during the crop cycle. Be aware that this timeline is **not universal** and can change depending on the crop and the location (Figure 34).

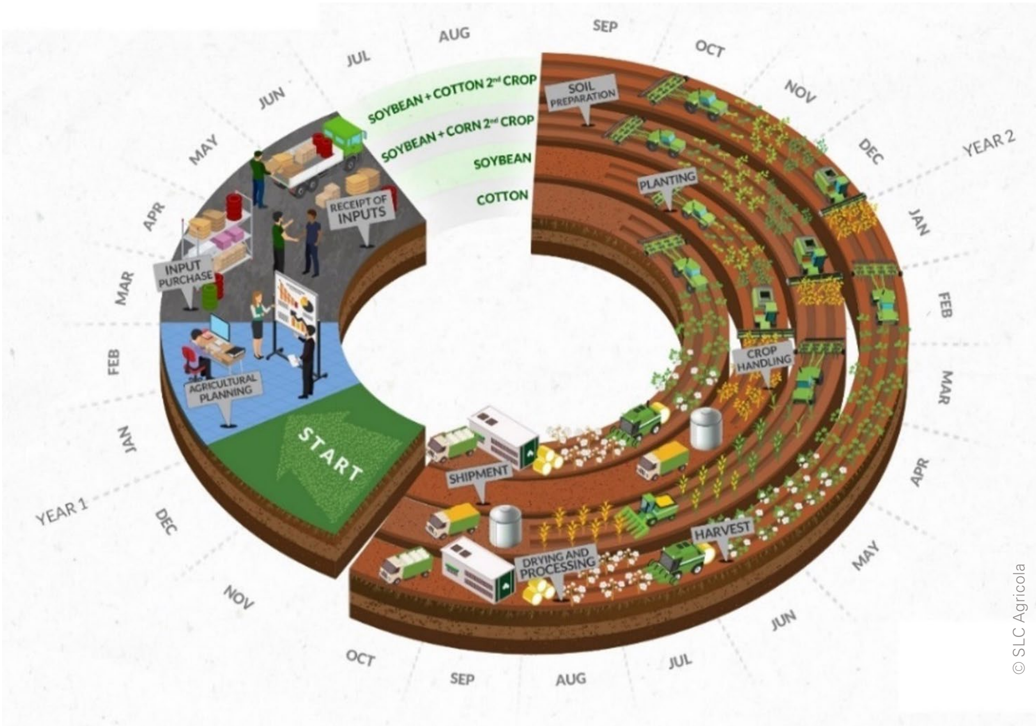

Figure 34: Schematic timeline of on- and off-field operations and processes for different crops

A. Overview of machine options for specific field activities

Exercise: Cropping calendar for rice and maize with visualizations of field operations and implements

To set up a timeline like this, make a list of all field operations and identify the time of the year each activity should ideally be done for every crop. Field operations include land preparation, sowing or planting, fertilization, weed and pest control, harvest and post-harvest activities such as drying, shelling and milling. In Figure 35, an overview is given of the most common pre-season, in-season and post-season activities for most open-field crops.

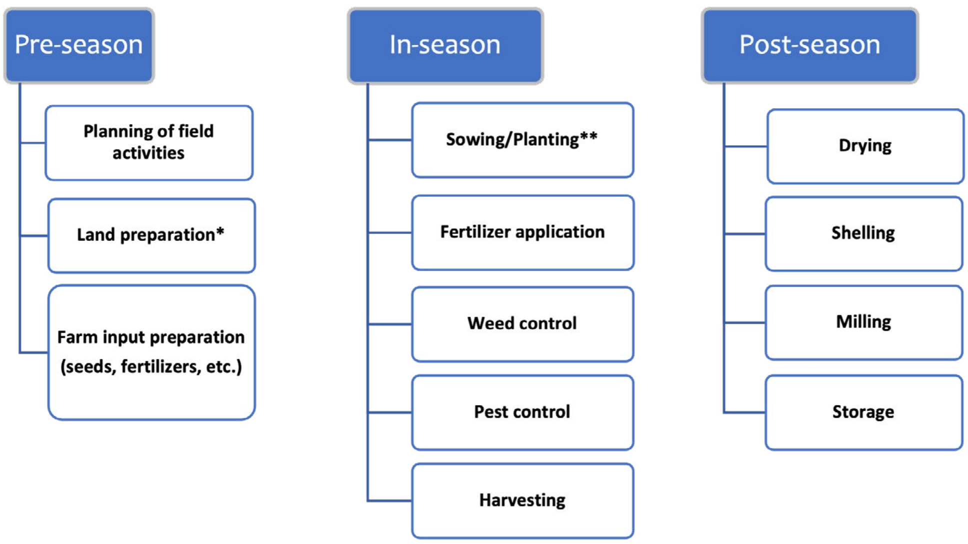

Figure 35: Overview of main activities, field operations and postharvest tasks performed as part of a general production system (* land preparation is not an annual activity per se, ** includes direct seeding or transplanting)

Make a list of all activities throughout the year and place them on a timeline to generate a graph similar to Figure 36. Specify the number of hours or days devoted to performing each activity per month to help you identify peak activity periods. In the example in Figure 36, activity peaks can be identified as harvest (**C**), which often has to be realized in a very short time, and period **B**), which is when many activities take place simultaneously (like fertilizer application and weed control, shortly after planting). On the other hand, land preparation activities (**A**) like land preparation, bed-making or post-harvest processing might be possible to realize in a less time-constraint window. Through this kind of exercise, one knows when to be prepared and when to schedule machine support. This type of planning is also essential for the agri-businesses providing mechanization services in rural communities to help them understand what pieces of equipment are needed at any certain time, thereby offering farmers the right kind of support in times of need.

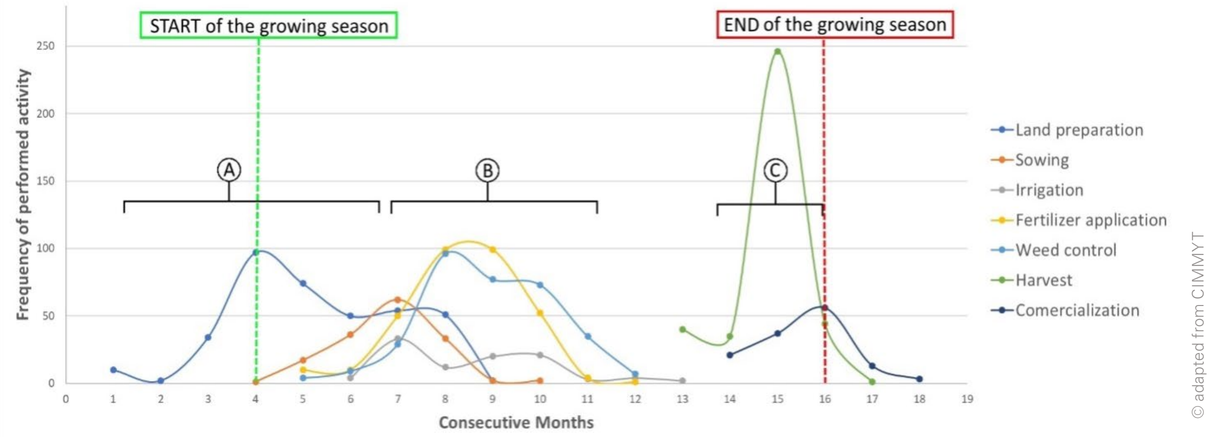

Figure 36: Timeline of field operations, with a relatively broad window for land preparation activities (A), a very intensive period with multiple tasks to be performed after sowing/planting (B), and a very short and critical harvest period (C)

The following sections will present machinery for specific field operations in detail for both 4WT and 2WT. It is important to note that not all equipment is suitable for every farm or production system. For example, in conditions that allow for improved farming practices, machinery that supports conservation agriculture principles (i.e. minimum soil tillage, soil cover, and crop diversification) is the recommended option. Over the years, many implements have been developed that allow growing crops with reduced or no-tillage, such as the direct seeding (planting) of crops into the soil covered with crop residue from the previous season, mulch cover, or with living cover crops. These are often also nitrogen-fixing leguminous crops that improve soil fertility.

The objective of this module is to give an overview of the currently recommended machinery from a sustainable agricultural viewpoint. The manual will also point out the potential negative impact that certain tillage-based equipment has on soil erosion, leading to the loss of topsoils caused by intensive tillage operations.

B. Land preparation equipment

Land preparation is a common term for a broad group of activities that are performed in the field before the onset of the growing season. Simply, it refers to preparing the soil to receive the seeds to ensure good crop establishment, uniform plant density, and adequate plant arrangement that allows movement of other machinery or people during the growing season for tending the crops. Activities include land levelling, soil turning to eliminate compaction, surface ploughing to loosen up hard soil macroaggregates, removing or trimming vegetative growth that emerged in the fallow season, ridging for gravitational irrigation, digging drainage canals, bedmaking, harvesting water in the field, and so forth.

The FAO sustainable agricultural mechanization (SAM)[1] and related conservation agriculture (CA)[2] concepts promote alternative land preparation methods to reduce labour requirements, drudgery and the negative impact of heavy tillage on soil health. It also increases the efficiency of field operations and production sustainability. Reduced and no-tillage, direct seeders, knife-rollers, and tined tillage equipment can contribute to achieving this objective.
More practically, it is fundamental to make sure that the main structure of the land preparation equipment is in good condition before taking it to the field, as many parts engage directly with the soil, and minor deteriorations might cause the structure to break during operation. One should also make sure the tractor to be used has sufficient power to pull the selected equipment through the soil. In the context of SAM and CA, 2WT are ideal, especially for smallholder farmers (plot sizes in the range of 1–2 ha) as they are great working platforms to pull direct seeders or strip-till-like toolbar equipment. But due to their limited horsepower and pulling power, they can less so carry out heavy tillage operations.

Four-wheel tractor

The FAO SAM and CA unequivocally favour tined tillage equipment (rippers, subsoilers, cultivators) over equipment that inverses the soil, like disc plough, harrow and rotavators. For this reason, promoting the conventional heavy tillage tool should only be done in limited cases such as first-time land clearance and bush clearance or for breaking hardpans in compacted soil. The recurrent breaking of soil aggregates and subsequent pulverization of soils burns the soil organic matter and erodes the finer soil particles causing the soil to become increasingly sandy, losing its ability to hold nutrients and inputs. We will therefore discuss alternative equipment first to facilitate sustainable land preparation methods.

- Strip-till and chisel ploughs

  The strip-till and chisel plough attachments are two examples of land preparation implements that, instead of turning over the soil and breaking its structure, only perform vertical tillage of the soil (Figure 37). Chisel ploughs are mainly used to enhance water penetration in superficially compacted soil layers and aerate the soil without lateral movement. Strip tillage has a similar effect to reduced tillage as it leaves >50 percent of the soil intact. This is particularly used in fields undergoing CA, where linear strips are cut into the upper soil layers and through the crop residue in which seed will be deposited, thereby retaining the crop residue. This method can be quite useful in dry heavy soils that resist the penetration of direct seeders at a single passage. Compared to full tillage equipment, this method requires drastically less fuel.

1 fao.org/sustainable-agricultural-mechanization/en

2 fao.org/conservation-agriculture/en

Figure 37: A chisel plow (upper – left) and right and strip-till implement (lower), performing vertical tillage to provide grooves for water infiltration and loosen up hardened soil for direct seeding, cutting through the crop residue.

- Subsoiler

A subsoiler is an example of a corrective deep tillage implement that was specifically developed to break up subsoil layers that are compacted due to the cumulative effect of yearly tillage activities using the moldboard or disc plough (Figure 38). This equipment requires a strong tractor (60–100 hp needed for one subsoil point) to pull the subsoiler as deep as 70 cm into the soil, and therefore fuel costs can run high. When used at the right depth, time (at the end of the growing season before the soil is completely dried out), and frequency (only as a corrective measure every couple of years in heavily tilled soils), this equipment can be very effective, including in improving drainage in water-logged soils. Subsoil points are prone to wear and tear, and different tips, including ones with horizontal wings, can be added to increase the width of the subsoil layer to be loosened.

Figure 38: Levelling scraper knife manually controlled by means of the tractors' hydraulics (left) and laser land leveller with automated mechanism (right)

- Levelling and contour-levelling

More specialized corrective equipment, like levelling scrapes, can fill small depressions or reduce mounts on mildly uneven fields, thereby flattening the farmland, improving crop uniformity and optimising water management. Using a scraper knife pulled behind a tractor, one can either manually adjust the scraper height with the tractor's hydraulics following visual queues for flatness or automatically with a laser-guided depth-control system and a control beacon (Figure 39). In the latter case, the levellers can be programmed to level the land with a certain inclination angle facilitating gravitational irrigation and drainage. Levelling should only be considered as a one-time improvement job on terrains with dispersed and light depressions, but the equipment can also improve field access by paving small roads between fields or smoothening community paths.

Figure 39: Levelling scraper knife manually controlled by means of the tractors' hydraulics (left) and laser land leveller with automated mechanism (right)

Levelling large parcels of sloped terrain is simply not feasible because of the large mass of soil to be moved, but contour-levelling can be opted for to reduce water erosion. In this case, strips of land are levelled at different heights following the natural relief to create either terrace-like features using a scraper or single seedbeds using a ridger, in a step-wise fashion (Figure 40).

Figure 40: Contour-levelled land in broad strips following natural topography (left), and contour levelling performed with a ridger before and after plant germination (centre) and (right)

- ## Biomass and crop residue management

Weeds and other invasive vegetation will likely take hold of the land during the fallow period. When preparing the land for the next cropping cycle in such case, one can use roller-crimpers (also called knife rollers) to flatten and crush the growing vegetation or shedders, rotary cutters and mowers to trim grasses and shrubs. Roller-crimpers are heavy cylinders with sharp-edged blades that can either be pulled or pushed by a tractor, while shedders and mowers need a PTO connection to operate the rotating blades (Figure 41). These implements can be used in CA, where fallow vegetation or cover crops are preferred to be left on the topsoil.

Figure 41: A knife-roller or roller-crimper being pulled by a tractor crushing the vegetation (upper left and right) and a horizontal shredder/mover trimming maize stubble spreading the crop residue evenly over the field (bottom left and right)

- ## Ridgers and dammer-dikers

Ridgers are likely the most common tractor implements to be found, as they fulfil the basic purpose of making ridges on agricultural land. With it, plots can be delineated, furrows made, and borders carved. A wide variety of ridgers in all sizes and shapes exist, all with some degree of advantage for a certain task and specific soil. Broader ridgers are generally used to elaborate inter-plot divisions and borders, while narrower point ridger units are used for seedbed reshaping and in-crop cultivation (Figure 42).

Figure 42: Two different types of ridgers; on the left, a ridger often used to create plot borders and on the right, a wing-shaped ridger more commonly used for bed-making.

Similarly, dammer-dikers are a special kind of furrow-shaping machine and consist of shovel-like implements to be pulled by a tractor as a single unit or combined for simultaneous operation in three or more rows. Passage in the field with a dammer-diker creates small pockets within the furrow that capture and retain rain during the growing season. This is performed as a water harvesting technique (Figure 43).

Figure 43: A rotary dammer-diker punching water harvesting holes in the furrow (left), and shovel type dammer-diker unit that can be attached on a frame to create rectangular shaped water pockets

- Disc plough & harrow, rotavator and moldboard plough

The plough, disc harrow rigs, and rotavators seemingly and traditionally have the same basic function – inverting the soil to uproot weeds, softening the soil to establish a seedbed, and burying crop residues. Nonetheless, in intensive farming systems, these implements have been shown to have a devastating effect on soil organic matter content and soil structure, including subsoil compaction known as plough pans. Therefore, they are mentioned in this manual only for completeness' sake and are not recommended as per FAO's framework under SAM and CA.

Rotovators are commonly used for secondary tillage like the disc harrow, but they break up the soil to the point of pulverization. The implement has curved blades on an axle that rotates fast as it is pulled over the soil with the rotational velocity provided through the PTO of the tractor (Figure 44). As this machine requires more power, tractors used to operate rotavators should have 40 hp per metre of operation width (65 hp for a regular 1.6m tractor gauge). It is recommended to only use rotovators superficially as they can be quite effective for shallow tillage and scraping the surface for weed clearance. Beware, however, that frequent use of rotavators on heavy clayey soils causes compaction leading to plough pans due to repetitive destruction of upper soil structure. As such, this feature makes them suitable for puddling rice fields. By changing the blades, the rotavators can be used to incorporate crop residue superficially.

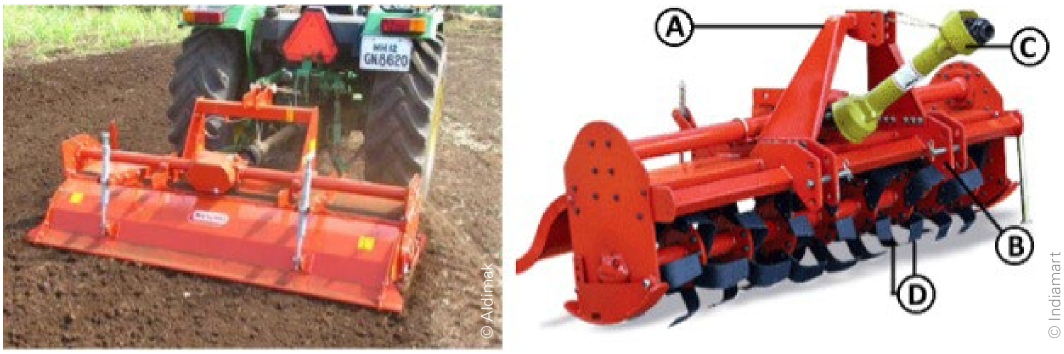

Figure 44: A rotavator attachment pulverizing the soil as secondary tillage, with main components, namely (**A**) central hitch tower, (**B**) lateral hitch pint, (**C**) PTO connecting rod, and (**D**) C-shaped rotavator blades

A more traditional piece of equipment for loosening virgin land is the moldboard plough: a wing-shaped plough that slices and inverts the soil in rough layers. The moldboard plough comes with varying numbers of moldboards; a plough with three to four moldboards can be pulled with an 80 hp tractor. Although useful to bring new land into cultivation, the before-mentioned implements are better and more sustainable for primary tillage on existing farmland with continuous cropping activities.

Two-wheel tractor

Although many implements for 2WT are merely small-scaled editions of the same implements that were discussed above in the four-wheel tractor section, walk-behind tractors are lightweight and easily manoeuvrable, facilitating work on smaller and hardly accessible fields, including sloped terrains. The smaller engines make them more fuel conservative, but their restricted torque and reduced pulling strength prevent their use for deep soil tillage. Land preparation equipment for 2WT is therefore generally limited to shallow soil operations, making it increasingly favoured for sustainable farming practices for smallholders. Their attachments usually consist of only one single unit pulled behind the 2WT This section will not repeat the equipment seen before but will review the more common implements. For smallholder farmers, 2WTs are enough to perform land preparation operations.

- Rototiller

The rototiller or power tiller is a popular implement to perform land preparation activities with the 2WT. Similar to the rotavator for four-wheel tractors, this implement consists of a rotating axle on which curve-shaped knives are placed. The configuration and shape of the knives can be changed according to needs and soil conditions. The power tiller can pulverize the soil up to approximately 15 cm depth (although the objective is to keep this shallower with 5 cm being sufficient) and facilitate bedmaking and weed removal. Therefore, smaller petrol 2WTs with a narrower wheel gauge are also used as cultivators deploying the rototiller attachment. Instead of pulverizing the whole topsoil, the knives on the rotating axle can be removed and configured for strip-tillage only, reducing soil structure damage while preparing the land.

For diesel engine 2WT, the rototiller is usually coupled to the (hidden) transmission gearbox for power take-off needed to operate the tiller knives. Often a lever is present that serves as a clutch to engage and disengage the rototiller while the tractors' engine is running; the wheel in the back provides depth control (Figure 45). For some models, a driver seat is provided as well, and in this case, the depth control wheel functions as a steering wheel operated with the feet. For the smaller petrol engines, the main wheel axle of the tractor can be interchanged with an axle with tiller blades and directly operated with the 2WT engine engaged.

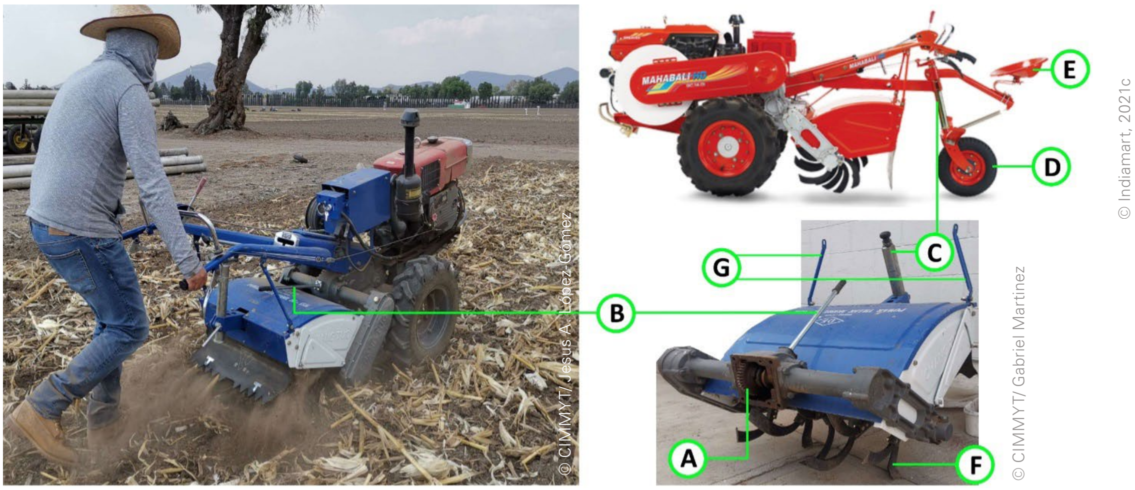

Figure 45: A rototiller of power tiller in action (left), and its main components with (**A**) transmission gearbox, (**B**) clutch, (**C**) depth regulating lever, (**D**) riding or depth control wheel, (**E**) operators' seat, (**F**) curved rototiller blade, and (**G**) additional support for attachment to a two-wheel tractor (upper right and lower right)

- Puddlers

Puddling is the tillage of rice paddy fields while flooded to destroy macroaggregates and churn the clay particles in the soil. This converts the soil into a homogenous mass of particles that, when settled, are packed together and seal the soil profile, thereby reducing the percolation of water. Although depth and intensity of puddling vary across regions, shallow puddling (0–5 cm) has proven to produce similar results to deep puddling (10–15 cm) in terms of rice yields and water efficiency, but with less soil compaction, facilitating root development of following crops and ensuring their optimal yields. Like shallow and reduced tillage, shallow puddling, therefore, is preferred.

A rotary or circle puddler can be used for this and is easily managed by a 2WT using cage wheels. In some cases, farmers build a sledge-type seat on top or behind the ensemble, which is especially interesting with 2WTs with longer handle arms (Figure 46).

Figure 46: Rotary circle puddler to perform primary tillage in wet paddy fields

During the same crop cycle, a paddy leveller is used to smooth out the mud and create a level soil surface, often as a second passage in paddy fields. Additionally, the implement softens the topsoil and facilitates the transplanting of paddy seedlings with knife-like extensions that go into the mud layer. If no other options are available, a regular piece of wood of the same length could also be used as a leveller. The operator can control the depth of puddling to a certain extent by standing atop the leveller or can just walk behind the working tractor (Figure 47).

Figure 47: Wet paddy field leveler to smoothen and loosen the top mud-layer before transplanting (right)

- Shredder and roller-crimper

Like implements for 4WTs, 2WTs also have implements that cut down vegetation that emerged during the fallow period. For some smaller petrol engines, a shredder/mower is available that can cut grasses and small brushes (Figure 48). For the larger type 2WTs, roller-crimpers can be used to crush the vegetation and dice it up for faster wilting and drying of the biomass. As in the case of 4WTs, this implement is often used for conservation agriculture purposes, as cover crops and crop residues are to be treated this way prior to direct seeding. This action is part and parcel of the FAO CA and SAM concept since it greatly reduces or eliminates tillage operations.

Figure 48: Two-wheel tractor operated roller-crimper (left) and small brush shredder/mover frontally attached to the PTO of a petrol engine 2WT (right)

C. Bed planting, direct seeding and fertilizer equipment

One of the most important operations during the cropping cycle is planting or seeding. Being able to do this with agricultural machinery saves time and increases precision on the field, resulting in higher cost-efficiency. The same goes for fertilizer equipment, by which the use of machinery for fertilizer applications makes it a lot easier to properly regulate the dosage and evenly distribute on the field the amount available, especially in situations where not a lot of extra money is available to buy inorganic fertilizer.

Direct vs. conventional seeding

Direct seeding in Conservation Agriculture (CA) systems refers to the practice of directly depositing seeds into the soil without prior tillage. In this context, direct seeding is synonymous with minimal or zero-tillage farming that aims to protect the soil structure, minimize run-off and erosion, reduce tractor usage (less fuel burning) and nutrient loss. Necessary equipment must be available to perform direct seeding successfully, including the presence of inverted T-shaped tines and/or cutting coulters that facilitate seed deposition even when crop residues from the previous cycle are present. More so, direct seeding allows cultivation on permanent seedbeds that only require reshaping of furrows when needed, producing co-benefits for controlled traffic and more efficient gravitational irrigation.

In conventional farming schemes, heavy tillage is common, which inverts, breaks up (or even pulverizes the topsoil at a 15–30 cm depth to provide a soft seedbed and rid the land of weeds or crop residues. However, by breaking down the soil structure and destroying soil micro and macro-aggregates, soil organic matter decomposes faster and residual roots are lost, leading to increased susceptibility for soil erosion and decay of microflora and fauna. Soil compaction and the creation of plough pans is a medium-term result of conventional farming and heavy tillage practices where the loosened topsoil sits on top of a compacted subsoil, impeding root and water penetration.

Therefore, in the transition from conventional farming to more sustainable farming practices, like CA systems, the focus should lie on reducing tillage, increasing soil organic matter and safeguarding the soil's living organisms. Therefore SAM refers to the use of farm tools and equipment that facilitate the transition towards and implementation of these improved practices.

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Finch, H.J.S., Samuel, A.M. and Lane, G.P.F. (2014). Cropping techniques. In: H.J.S. Finch, A.M. Samuel and G.P.F. Lane, eds. Lockhart & Wiseman's Crop Husbandry Including Grassland (Ninth Edition), pp. 193-217. Sawston, UK, Woodland Publishing. doi.org/10.1533/9781782423928.2.193

Main components and general recommendations

Seeders and fertilizers for both four-wheel tractors and two-wheel tractors are quite similar in design. They consist of the same main components, including a sturdy frame (**A**), containers or bins of varying size and volume (**B** and **C**), soil-engaging components to guide and deposit the seed or fertilizer to the soil (**G**, **I**, **J** and **K**), seed or fertilizer metres systems (**D**) and a drive train with calibration mechanism (**E** and **F**) (Figure 49).

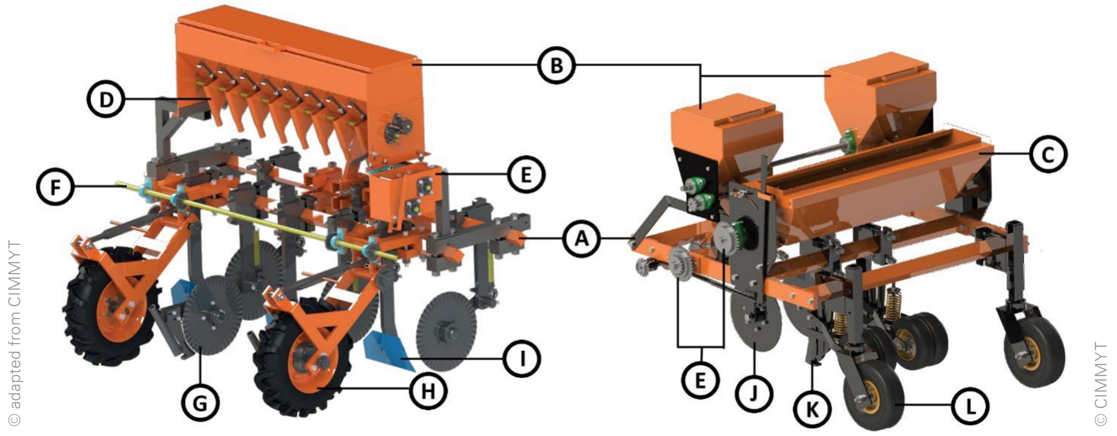

Figure 49: Fertilizer machine to be attached on 4WT (left) and 2WT seeder/fertilizer equipment (right), with (**A**) toolbar frame, (**B**) fertilizer bins, (**C**) seed container, (**D**) fertilizer metreing system, (**E**) calibration box, (**F**) principal axle, (**G**) cutting disc with fertilizer tine, (**H**) traction wheel, (**J**) crop residue cutting disc, (**K**) dual seed/fertilizer tine, (**L**) depth control wheel.

There is not much difference between a seeder and a fertilizer for small cereals like wheat and barley, as both use mass-flow metering devices. This means that a continuous stream of seeds or granular fertilizer formula is liberated from the containers or bins and deposited on the soil without interruption, unless during turns at the end of the field when the machine is lifted from the ground. Whether by mechanical, electrical or hydraulic movement, the metre devices turn at a pre-calibrated and constant rate, and seeds or fertilizer are deposited in several lines on or in the soil. Especially for granular fertilizers, it is important to have an agitator in the bottom of the fertilizer bin to avoid compaction and clogging (Figure 50). This can be as simple as a fingered moving rod or worm screw.

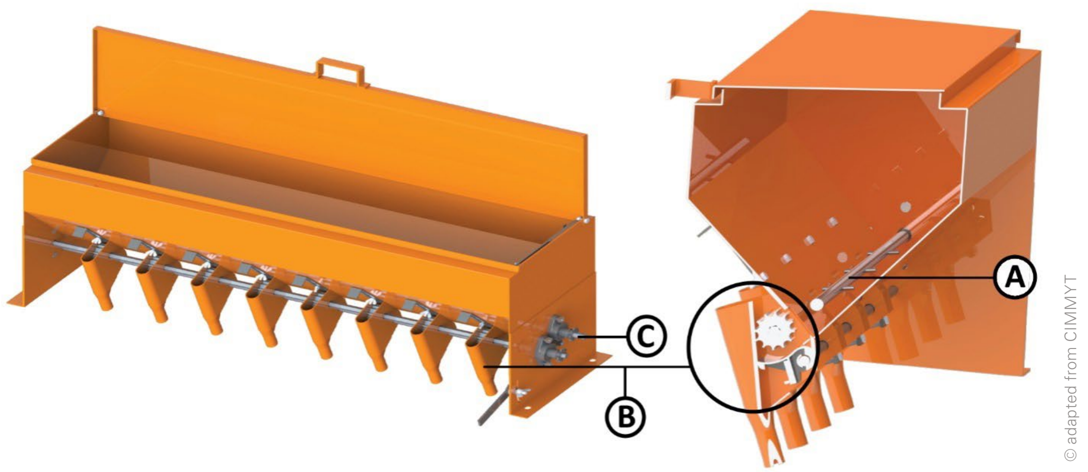

Figure 50: Close-up look of standard small cereal or granular fertilizer hopper, with (**A**) agitator that avoids compaction and fills the metering devices (**B**), and driving axles (**C**) running across the width of the container.

Exceptions to this depositing system are broadcasters that spread granular fertilizers in a circular motion evenly over the field (Figure 51). These fertilizer machines can be cheaper and more straightforward to operate but are less efficient, as much of the fertilizer is dropped far from the plants and ends up either leaching away with heavy rains or volatilizing. Nonetheless, the overall advantage of mechanically applying fertilizer over manual application is that the fertilizer is distributed evenly across the field and not influenced by fatigue and/or operator level of experience.

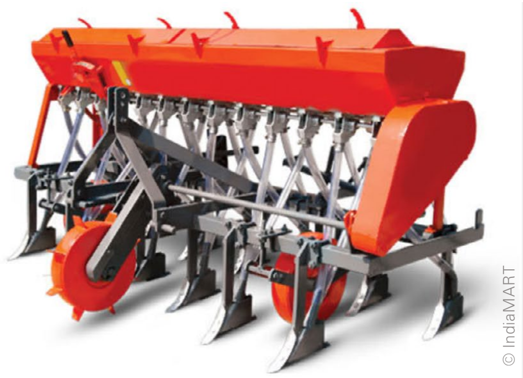

Figure 51: Generic mechanical fertilizer machine with traction provided by a spiky steel wheel rolling over the soil (left) and broadcast fertilizer application (right)

For large seeds, like maize and beans, the situation is slightly different as the choice of seed metering device can have a strong influence on seeding performance. As large seeds normally need to be isolated and deposited one by one in a discontinued fashion – also known as seed singulation, corresponding metering devices are, therefore, sometimes called precision seed metres. Many mechanical seed metre solutions have been proposed to achieve high precision at the lowest cost, mainly using seed plates or rollers with holes of different sizes to accommodate different crops (Figure 52). Any of these seed metres can achieve near-perfect performance when closely fitting the seeds. But when using ungraded seed or seed mixtures, horizontal and inclined plates metering devices often provide a better overall singulation rate and minimal seed damage.

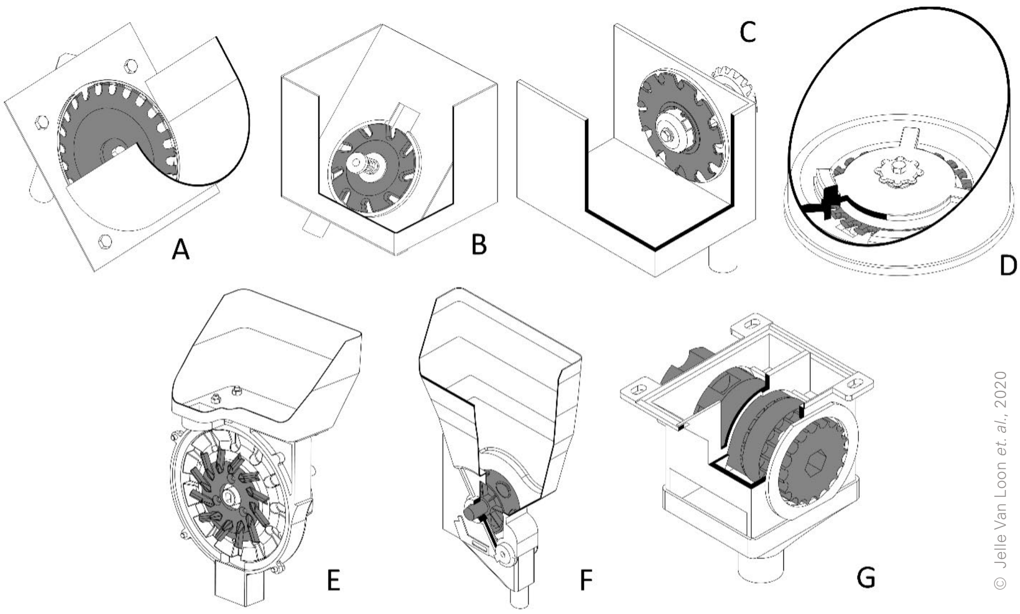

Figure 52: Different types of large grain mechanical seed metering devices, with inclined plate models (A & B), a vertical spoon plate system (C), a horizontal plate type with expulsor (D), vertical finger plate system (E), celled roller type (F), and a dual fluted roller type metering system (G)

As was seen in Figure 49, some machines are equipped for both fertilizer application and seeding, making them cost-effective through their dual purpose. Still, more specialized equipment and seed metres exist, increasing deposition efficiency and further reducing seed damage. Such is the case for pneumatic seeders, which use a turbine to generate air pressure into the metering device to improve seed singulation (Figure 53). Although highly efficient, these machines require more fuel as a turbine is spun by attachment to the tractor's PTO. They also are more costly and require more maintenance. Nonetheless, this may be a good choice when seeding large land surfaces or with graded seeds or hybrids, which are generally more expensive.

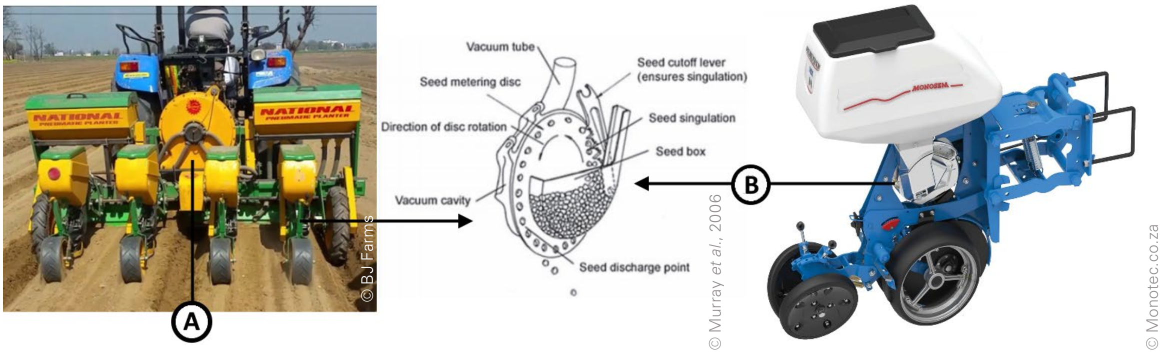

Figure 53: Neumatic precision seeder system, with (**A**) PTO-operated turbine to produce air pressure in the seed singulation chamber (**B**)

Calibration and configuration

Independent of the metering system, seeder and fertilizer machinery must always be calibrated to ensure the right amount of seeds or fertilizer is deposited on the ground. With electric and hydraulics engines, this might be as simple as turning a valve for the metres to work at a slower or faster speed to deposit more or less material, independently of the tractors' forward-moving speed. However, most mechanical systems either need a connection from the PTO to operate or have a separate mechanism that transfers the movement of the wheels in contact with the ground through the drive train to all connected moving parts. In either case, this transmitted rotational velocity is dependent on the operation speed of the ensemble (tractor and attached machine) and will therefore have to be calibrated in most cases to ensure the right seed or fertilizer quantities are released from their containers.

The calibration process is essential to be performed before starting work on the field and should be done with care as not to waste seeds or fertilizer during operation. Making the distributing axles turn faster or slower is usually performed by changing the size of gears or sprockets that are mounted on them as part of the drive train. In some cases, a gear or calibration box is present, which allows selecting the right combination of gears on the principal axle (Figure 54), and often an indication of what combination to select is provided in the form of a pre-calibration table provided in the manual or placed on the machine (Figure 55).

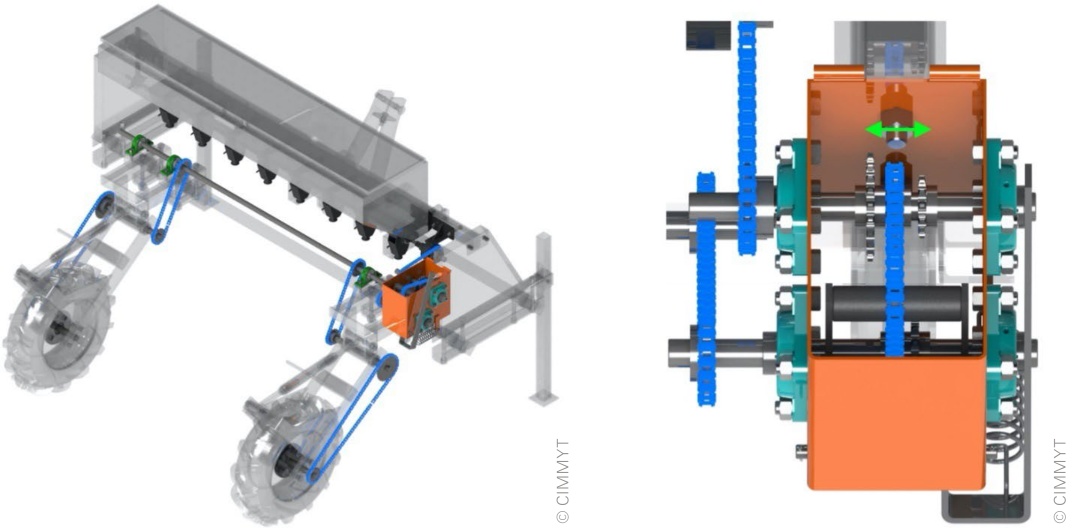

Figure 54: Fertilizer machine with drive train, including principal axle, transmission chains and gearbox for calibration accentuated (left), and close-up view of calibration box with medium gear combination selected (right)

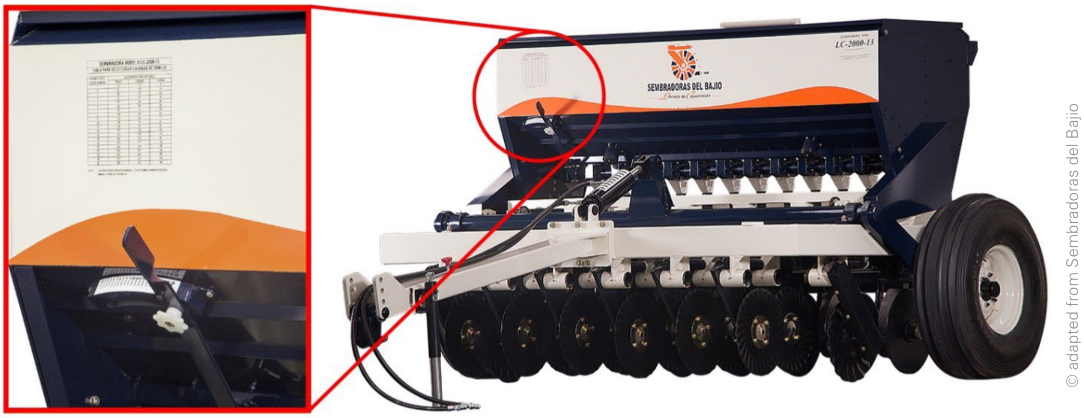

Figure 55: Calibration table on wheat seed drill and lever to adjust for seeding rate

What is topological arrangement?

The topological arrangement refers to the geometry between plants on a field, i.e. the arrangement of plant rows and corresponding seed lines or plant beds on the field. It consists of determining the most convenient distance between and within plant rows, resulting in an optimal planting density (number of plants per hectare), considering the specific production conditions (Figure 56). Planting density should be well thought out, as this enables plants to reach their full potential in local conditions by minimizing nutrient competition between plants. The machinery to be used during the cropping cycle and the yield potential of the land and crops, including germination percentage, should be accounted for when determining the appropriate planting density.

Example:

- If the inter-plant distance is 15 cm (0.15m) and spacing between plant rows is 80 cm (0.8m), then plant density is calculated as follows.

$$Plant\ Density\ = \frac{1}{interplant\ distance\ (m) \times interrow\ distance(m)} \times 10\,000\ m^2$$

$$= \frac{1}{0.15m\ \times 0.80m} \times 10\,000\ m^2 = 83\,333\ plants/ha$$

- If the conditions on the field do not allow for this plant distribution, because perhaps an intercropping system demands broader spacing between plant rows (e.g., 90 cm), the same plant density can be maintained by decreasing the number of plants within the plant row.

$$Interplant\ distance\ (m)\ = 1/\frac{plant\ density\ (\frac{plants}{ha})}{10\,000\ m^2\ \times interrow\ distance(m)}$$

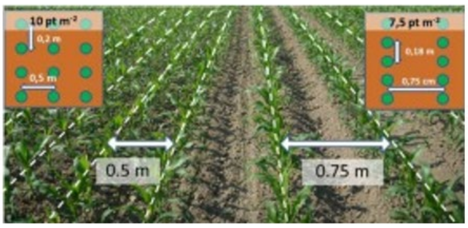

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Figure 56: Schematic of 2 different topological arrangements of maize, but maintaining the same plant density

Steps for calibration of large seeds:

1. Attach the seeder to the tractor, place the tractor with attachment on an appropriate calibration area (an unobstructed area to freely move back and forth with the tractor for at least five metres), and turn the engine off.
2. Locate the drive train and interchangeable gears.
3. Predetermine planting density (plants/ha) and topological arrangement (interrow and interplant distance).
4. Determine the calibration surface area.

$$Calibration\ surface\ area\ (m^2) = interrow\ distance\ (m) * lineal\ meter\ (m)$$

5. Determine seeds per lineal metre.

$$Seeds\ per\ lineal\ meter = \frac{plant\ density\ \times calibration\ area\ (m^2)}{10\ 000\ m^2}$$

$$= \frac{62\ 500\ plants/ha\ \times 0.80\ m^2}{10\ 000\ m^2} = 5\ seeds\ per\ meter$$

6. Place the drive train chain on an intermediate set of gears and start the tractor.
7. Move forward a minimum of 3 metres, with the attached machine just touching the ground but not cutting into the soil.
8. Stop engine and select with a flexometre a segment of one metre in the middle of the carved lines with seeds.
9. Count the deposited seeds in the line on the ground.
10. If the number of seeds exceeds the desired seed per lineal metre, choose a different gear combination that makes the metreing axle turn slower.
11. If the number of seeds is lower than the desired seed per lineal metre, select a set of gears that makes the metering axle turn faster.
12. Back up the tractor with the machine disengaged to its original position and repeat until the right combination is found.
    a. A slight deviation of seeds per lineal metre is expected. In general, a deviation of 5 percent or less is acceptable.
    b. For a predetermined five seeds per lineal metre, this means that 4.6 or 5.4 seeds per metre is accepted (between 9 and 11 seeds every 2 metres).

For smaller grains and granular fertilizer, the calibration process is very similar, with the only exception of the weight to be deposited per lineal metre is calculated and measured, accounting for the uninterrupted deposition of the seed or fertilizer. Further, instead of dropping the seeds or fertilizer into the soil, bags are placed at the exit of the metering devices. In addition, many mass-flow metering devices have mechanisms to fine-tune each device for increased precision and in case wear and tear produces individual differences between metres (Figure 57). The topological arrangement for fertilizer deposition can differ in seeding arrangements (between plant rows, next to plant rows, or in alternating plant rows, etc.), so this should be accounted for as well.

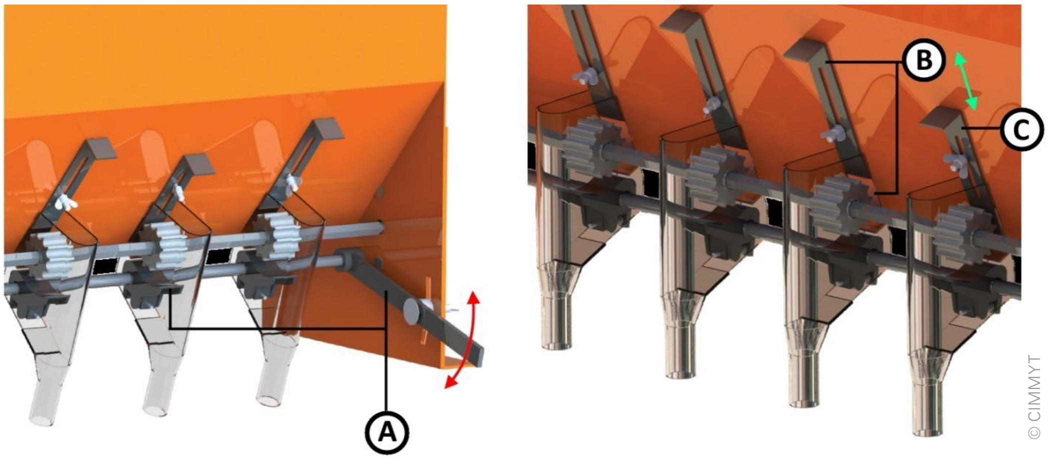

Figure 57: Close-up view generic fertilizer metering devices with internal components visualized that enable fine-tuned calibration with (**A**) bottom lip and adjustment lever and individual floodgates in open (**B**) and closed (**C**) positio

Steps for calibration for small seeds or granular fertilizer:

1. Attach the seeder or fertilizer machine to the tractor, place the tractor with attachment on an appropriate calibration area, and turn the engine off.
2. Locate the drive train and interchangeable gears.
3. Predetermine planting density or fertilizer distribution rate (kg/ha) and topological arrangement.
4. Determine the calibration surface area – for sufficient seeds or fertilizer to be deposited in the bags and to ensure accurate measurements, a distance of lineal 50 metres to advance with the tractor is recommended.

$$Calibration\ surface\ area\ (m^2) = \frac{machine\ working\ width\ (m)}{number\ of\ rows} \times lineal\ distance\ (m)$$

$$= \frac{1.60\ m}{4\ rows} \times 50\ m = 20\ m^2$$

5. Determine seeds per lineal metre.

$$Seed\ or\ fertilizer\ weight\ per\ bag = \frac{distribution\ rate\ (\frac{kg}{ha}) \times calibration\ area\ (m^2)}{10\ 000\ m^2}$$

$$= \frac{90\ ^{kg}/_{ha} \times 20\ m^2}{10\ 000\ m^2} = \ 0.18\ kg\ or\ 180\ grams$$

6. Place the drive train chain on an intermediate set of gears and start the tractor.
7. Make sure all metering devices have the same initial individual setting (Figure 58).
8. Place a bag at the exit of each metering device (**A**).
9. Move forward **exactly 50 metres**, with the attached machine just touching the ground but not cutting into the soil (**B**).
    a. A line can be marked at the front wheels of the tractor and another line 50 metres ahead, where the tractor stops.

10. Stop engine and collect the bags from each metering device, numbering each bag corresponding to an individual metering device (**C**).

11. Weigh the deposited seeds or fertilizer recollected in each bag and write down results (**D**).

12. If the measured weights exceed the desired amount, choose a different gear combination that makes the metering axle turn slower.

13. If the measured weights are below the desired amount, select a set of gears that makes the metering axle turn faster.

14. Back up the tractor with the machine disengaged to its original position and repeat until the right combination is found.

    a. If the average weight of all bags is higher than 10 percent below the desired quantity, try to adjust the individual metres of the bags that present the largest deviations from the desired weight.

    b. If the average weight of all bags deviates less than 5 percent, the machine is calibrated successfully.

Figure 58: Steps for the small-seed calibration process, with (A) placing bags to collect distributed seeds, (B) putting the machine on the ground to start calibration, (C) seed collected after 50 metres, and (D) weighing each individual bag to see it matches predefined quantity

There are other methods to calibrate a machine. When no room next to the field for calibration is available, one option for mechanical seeders/fertilizers working with a drive train is to measure the traction wheel circumference and divide 50 m (or any reasonable equivalent) by this amount. To produce the same results as the tractor moving, turn the wheel the number of times calculated with the machine lifted from the ground and use the bag method to count or weigh the deposited quantities.

Soil engaging implements – conventional and direct seeding typologies

Besides the metering devices, another essential component of seeders and fertilizers is the soil-engaging implements or depositing units. These units come in various combinations; they can be as simple as a tine or as complex as a five-piece rig with the same purpose to ensure proper guidance of the seed or fertilizer to the soil. A brief overview of options is given in Figure 59, where tines or chisels are mostly used on farmland free of stubble or crop residue. A combination of a tine with a cutting disc in front is more useful for cutting through top-layer crop residues and dried vegetation. More complex combinations can include a series of (double) discs, stubble clearers and soil compaction wheels. They all have their particular advantage but vary greatly in cost and weight and should be used while considering soil conditions and the tractor's capacity. Independent of combination, the main goal of any seeder is to provide adequate soil penetration to position the seed at the correct depth into the soil and provide a good seed-soil contact to stimulate germination. In the case of fertilizer, the objective is to place the right amount of fertilizer in the vicinity of the seed without damaging or "burning" it. For machines that are able to seed and apply fertilizer simultaneously, soil-engaging units often have double guiding tubes and position the fertilizer slightly above the seeds.

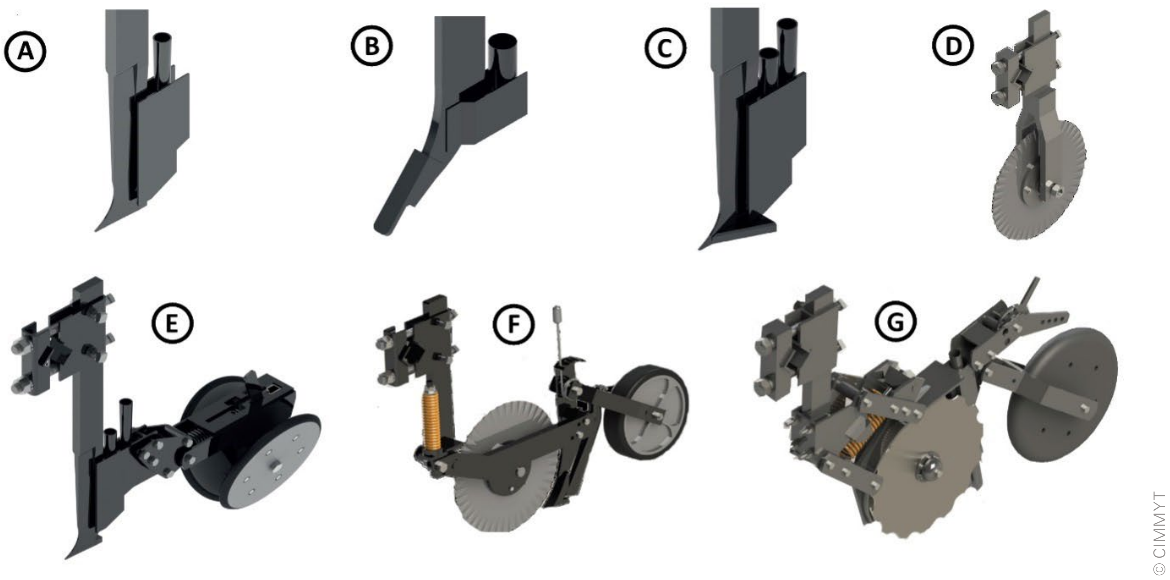

Figure 59: Series of soil-engaging units, commonly found on seeders or fertilizers, that aid seed deposition into the soil, with (**A**) standard tine, (**B**) burrowing fertilizer tine, (**C**) inverted T-tine with double tubing for simultaneous seeding and fertilizer application, (**D**) crop residue cutting disc, (**E**) single tine with v-shaped compression wheels for sandy soils, (**F**) cutting disc and single tine for buried fertilizer application, (**G**) double dented disc system with compaction wheel for direct seeding through crop residue layer

Many commercial seeders and fertilizers come in a specific setup of soil engaging operating units organized in a linear, parallel configuration. Sometimes, this configuration can be adjusted by sliding the operating units alongside different toolbars. This leaves a bit more flexibility to accommodate local needs but requires some thought beforehand, considering the crop and topological arrangement. A couple of examples are given in Figure 60.

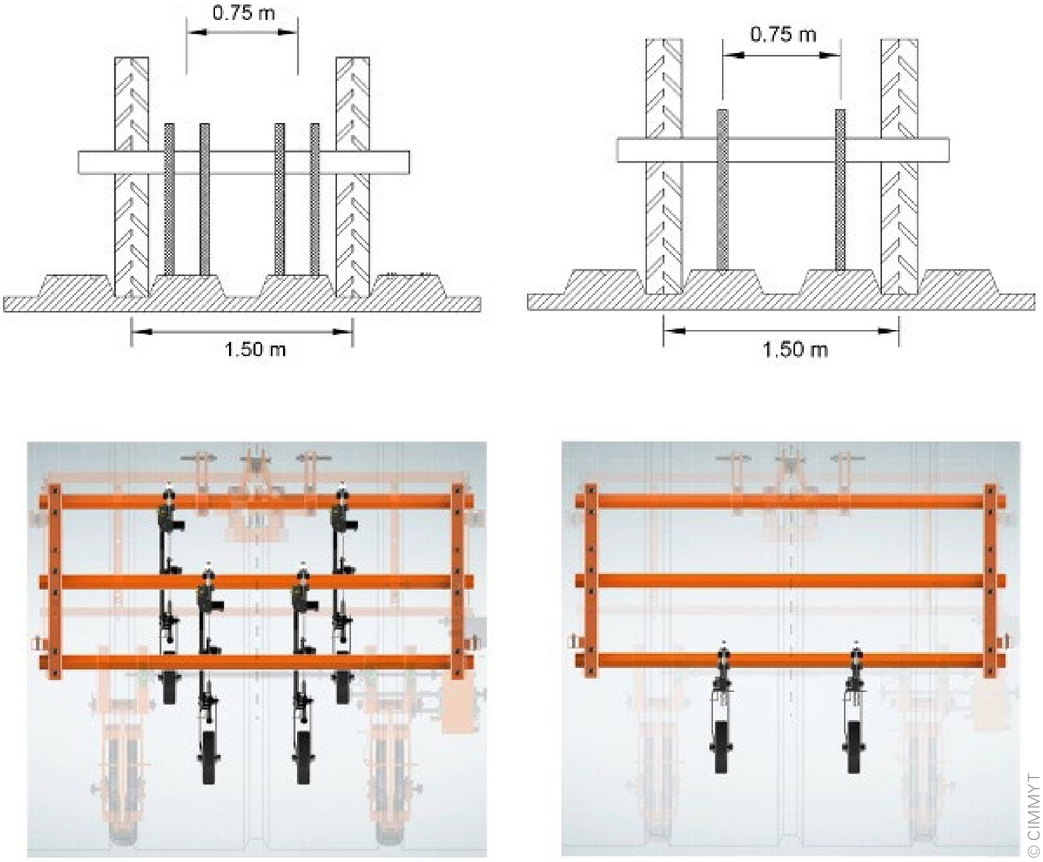

Figure 60: Standard single maize row seeding configuration (right) and double plant row configuration with 4 seeder units accommodated on a flexible toolbar frame (left).

Cleaning and general upkeep

To extend the life of any equipment, it is important to make sure all exterior and interior parts of the machines are cleaned after every use. A simple wash down with soapy water can be sufficient to get the mud off, especially since any crash or damage caused during field operation becomes visible during the washing. Make sure to dry the machines, especially the internal components to avoid oxidation. When cracks are spotted, make sure to clean them out properly and consider immediate repair. Often reinforcing existing welds can be enough to avoid larger repairs in the future. If the paint is chafed or damaged, consider touching up, at least with primer, to prevent rusting.

Especially for fertilizer equipment, it is important to clean out all remaining fertilizer from the container, metering devices and guiding tubes. Leaving it will cause severe oxidation to any metal parts due to the reaction with the humidity in the container. In addition, fertilizer tends to coagulate when moist, and this might jam and break any internal mechanisms if forgotten to be removed. For seeders, the same recommendation is given to avoid rodents or other pests nesting inside the equipment. Finally, review all moving components and lubricate were needed, as indicated in Module 1. Preferably store the machine in a shaded area covered with a tarp.

D. Water pumping & weeding

Of particular importance during the growing season is making sure the crops receive enough water and the weeds are eliminated to avoid competition for nutrients with the crops. Timing of these activities is critical to ensure optimal crop production and high yields.

Axial-flow pumps, mixed flow pumps and sprinklers

Water management depends more on narrowing down the right time for planting rain-fed crops. Still, using pump sets for (auxiliary) irrigation using temporary water bodies might be a good option to increase crop water availability. Small mobile engines, including 2WT engines, can be used to power pump sets fairly easily.

Axial-flow pumps (AFP), which consist of a large pipe (up to six metres long) that reaches the water reservoir and a propeller to thrust the water up, can lift water with the help of a small engine such as that of diesel-powered 2WTs. As explained in Module 1, the engine can connect to the pump through a v-belt that drives an axle down to the propeller positioned in the water. Most 2WT-powered AFPs can lift water as high as three metres with minimal fuel consumption (Figure 61).

Figure 61: Axial flow pump rigged to a two-wheel tractor using the v-belts, with a close-up of the propeller sucking up the water and diagram of the pump's internal mechanism

Radial pumps using an impeller instead of a propeller are more common and often cheaper as they only require a housing unit matching the size of the impeller. They are easy to move and install as flexible hoses can be used, and the impeller does not have to be in contact with the water source to start. They can provide high power output but require more fuel to push through the same volume of water compared to the AFP. When a water source is near and has to be pumped only over a small distance, this can be a good solution, even for the smaller petrol-engine type 2WT. The connection is either made with the v-belt or directly attached to the PTO or fly-wheel. Note that the pump has to be primed to fill the water column before starting, and any leaks in the hoses might result in losing significant pressure (Figure 62). Instead of letting the water freely run on the field, a pivoting sprinkler can be attached to spray water over a greater distance and more evenly.

Figure 62: Radial flow pump attached to PTO of a small petrol-engine 2WT (left) and attached directly to the flywheel of a diesel engine 2WT (right)

Cultivators and mechanical weeding

Weeding is another time-sensitive task that is high in drudgery if performed manually. Weeding is particularly important in the first 45 days after planting when the soil is still largely left uncovered by the crops, especially since weeds tend to grow faster than the cultivated crop. Tractor power can be used for cultivating or weeding as a safe alternative to spraying. Cultivators use scraper-like implements to remove weeds between crop lines and along edges mechanically, but other small motorized hand equipment is also available.

For 4WTs, the attached equipment consisting of V-shaped chisels on a toolbar frame can provide good results. The flattened triangular shape of the cultivator's tines aims to cover as much open ground between the plant rows and cut all weed roots by passing right under the soil surface. Different configurations can be used depending on the crops and topological arrangement (Figure 63).

Figure 63: Four-wheel tractor pulling a homemade cultivator to control weeds in the field during crop growth (left), and cultivator machine with triangular cultivator tines/scrapers (right)

For two-wheel tractors, the power tillers and the mini-tiller wheel axle can be used for the same purpose as mentioned before. Handheld mechanical or motorized devices are also becoming more common and are good alternatives on smaller plots. Some examples are given in Figure 64.

Figure 64: Examples of hand-held power weeders, with stroller and backpack system.

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Module 3

Harvest, postharvest and storage

This third module for the Training of Trainers (ToT) course discusses machines and equipment used during the final stage of the production process. Such machines and equipment, which aim to facilitate the handling and processing of food products on- or off-farm, are equally important as all the previously discussed, as they can greatly impact the final food value. In fact, postharvest losses and food wastes due to inadequate handling and storage can run up to 50 percent of the total yield if unattended. Therefore, this module will give an overview of common machinery that can help farmers harvest their crops quickly while significantly reducing losses and keep their harvested products safe, nutritious, and optimal for sale and self-consumption.

Session 3.1
Self-propelled harvesters and small-scale options

As explained in Module 2, crop harvesting at the end of the growing season often occurs at a forced pace, with a lot of work to be done in little time as crops on different fields reach maturity simultaneously. As such, the window of opportunity for harvesting is rather small, especially for grain crops. This is mainly due to predatory pests, like birds and rodents, that prey on the grain as soon as the tillers start filling and exposure to unfavourable (humid) weather conditions during grain maturation that could have disastrous outcomes infestation by molds and fungi. Hence, a speedy harvest is highly desired when full maturity is reached, highlighting the need for harvesters and reapers. Further, although speed is important, the quality of work is also essential, where one must ensure that the maximum number of undamaged crops can be recovered from the field. This process usually occurs in three steps: cutting the stalks, threshing the tillers or shelling the cobs in case of maize and subsequently cleaning the grain (or separating it from the husks). These steps can be performed either separately or in one simultaneous passage as is often done by large 'combine' harvester machines, hence their name. Although these large machines offer a solution when time is scarce, not all models offer the same efficiency in grain recollection, with reports of up the 30 percent grain spills to the field. For this reason and the sheer size of the combines, including the severe compaction of the soil they cause, they are not recommended for small unconsolidated plots. In response, this module will look into a couple of alternatives for smallholder farmers.

A. Options for small-scale mechanized harvesting

Many attached equipment for 2WT focus on field operations during the cropping cycle, but a couple of options are available to facilitate the harvest as well. Most common equipment are frontally attached mowers or reapers, although small self-propelled combine harvesters exist as well[3]. If unavailable or too costly for own purchase, manually-operated motorized tools can offer an alternative and intermediate solution.

3 For almost all two-wheel tractor mounted and/or self-propelled small-scaled equipment, general indications for operation are similar and include cranking up the engine as explained in Module 2 and identifying the lever or clutch that engages the attached equipment. For **reapers**, sometimes an additional handle is available that sets the cutting height of the frontally positioned cutting blades. **SAFETY NOTE**: When a machine hampers or gets stuck during operation, make sure it is turned OFF immediately and fully stopped, before removing stuck material and restarting. **During all times, be alert and stay clear of moving parts to avoid injury!**

Small-scale self-propelled or 2WT-mounted reapers

For small grains, like rice and wheat, many models of self-propelled reapers exist. The main feature is the reaper head that divides the standing crop with star-shaped fingers organized in lines that grasp and push the stalks towards a lugged-type blade chain that cuts off the tillers (Figure 65).

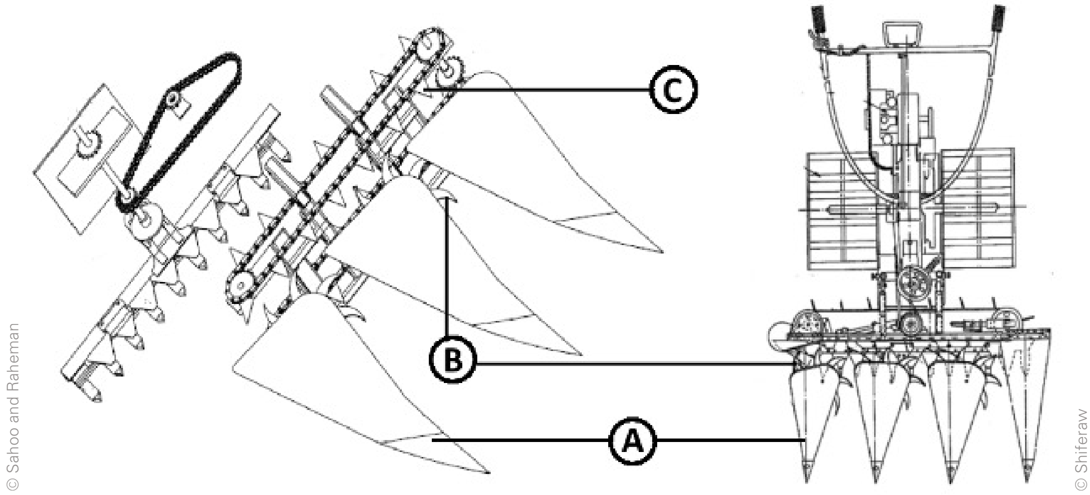

Figure 65: Diagram of a reaper machine (left) and mounted frontally on a two-wheeled tractor with steel cage wheel (right), with (**A**) crop dividers, (**B**) star-wheels that grasp the crops and guide them towards (**C**) the cutting blades on the lugged chain.

Often on larger diesel 2WT-mounted reapers, the cutting height can be adjusted, while for smaller self-propelled versions, this should be done manually by pushing the handlebars up or down. Subsequently, the cut stalks are dropped to one side of the field. Reaper-binders also can be found, where the cut-off stalks are roped together in bundles, making recollecting easier. A couple of 2WT and self-propelled models of both kinds are shown in Figure 66.

Figure 66: Different types of reaper equipment and its operation in the field (A) and (B), two-wheel tractor reapers (C) and (D), self-propelled petrol engine reapers) and ((F), and reaper-binders (G) and (H)

Self-propelled mini-combine harvester and single line 2WT maize harvester

Recently, an attempt has been made to develop small-scale c ombine harvesters to facilitatethe whole harvesting process of small fields in one step. These machines are slowly becoming better and more efficient. Either self-propelled or mounted on a walking tractor, these machines are equipped with similar components as large-scale combine harvesters, including frontal revolving reel and intake auger with cutter bar, a funnelling system with a ventilator for grain cleaning and a loading platform, often with room for 25 or 50 kg bags (Figure 67).

Figure 67: Small-scale self-propelled combine harvester options and its components, with (**A**) revolving reel, (**B**) intake auger or worm screw, (**C**) cutter bar, (**D**) thresher drum, (**E**) straw material outlet funnel, (**F**) grain collector tube and (**G**) collecting bags for clean grain. Note the option with (H) tracks, instead of tires on the green harvester on the right, which facilitates movements on mulchy terrains.

A similar evolution on the market has happened for maize harvesting, offering single row maize harvesters that chop the stalk and harvest the maize cobs. The collected corn cobs are de-husked and deposited in small mounds on the field for collecting afterwards (Figure 68).

Figure 68: Small-scale single line maize harvester type, with a two-wheel tractor version on the left and a self-propelled version on the right

Portable cutter with accessory for rice harvesting

Like the powered weeders discussed at the end of Module 2, small manual harvesters that can increase farmers' efficiency and field capacity have recently appeared on the markets. The cutter disk is simple and should easily adjust on motorized power mowers. Adding a separation shield enables gathering loose bundles of harvested rice or wheat stalk quickly (Figure 69).

Figure 69: Portable motorized cutter implements as an intermediate solution to mechanize harvest in cereal crops, with a hand-held version on the left and centre, and a back-pack carried version on the right. Notice how both models present a shield to gather the cut-off material to one side during operation.

B. A brief overview of rice combine harvester components and mechanism

This section gives an overview of a larger rice combine harvester setup. This is because at peak periods during the harvest season, small machines alone are likely unable to attend to the full demand. It focuses on the general components and functioning of the harvester's mechanisms, offering insights to farmers in areas with larger consolidated lands that are suitable for these machines.

Main structural components for harvesting are discussed, including the mechanisms underlying the three tasks of a combine harvester; cutting the grain stalks, getting the grain from the tillers or threshing activity, and separating the threshed grain from the husks and remaining crop residues. While some combine harvesters only perform these tasks and need an accompanying tractor with a container to hold the final grain product, others have the capacity to store the grain as they operate. The representation given here is one of the latter models.

As can be followed in Figure 70, in one single pass, the grain stalks are cut in front by the header platform (A) and moved on the feeder belt to the thresher hub (B) and subsequently to the cleaning or winnowing hub (C), after which the separated grain is collected and moved into the storage container (D); drive (E) and directional wheels (F) are added for completeness (note here that the rear wheels effectuate the steering).

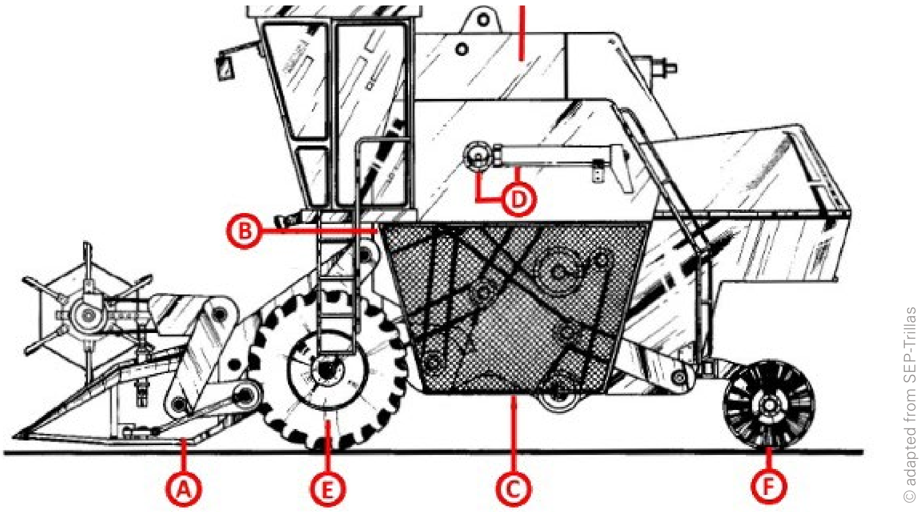

Figure 70: Diagram of a large-scale combine harvester, with main components, namely (**A**) header platform that performs the cutting of the crops, (**B**) thresher hubs to separate the grain from the straw, (**C**) winnowing or cleaning hub, and (**D**) grain collector tube and storage container. Traction or propulsion wheels (**E**) are frontal, while smaller guiding or directional wheels (**F**) are at the back.

Figure 71 gives a close-up view of the header platform. It is important to be aware of this component to ensure safety during operation and because parts are exposed and likely need the most direct maintenance and care. The crop dividers or separators (**A**) delimit the harvested strip on the field from either sides, while the revolving reel (**B**) pulls in the standing tillers, pressing them against the cutter bar (**C**) that is equipped with pointy triangular knives making a shearing movement. Next up is the intake auger or worm screw (**D**) that pushes all the cut-off material to the centre, where the turning fingers push the material on the feeder belt (**F**).

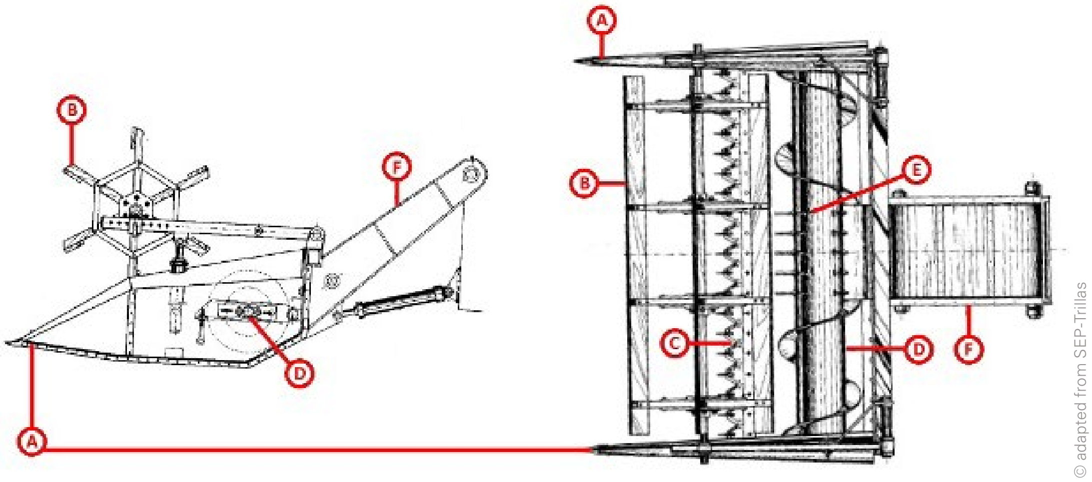

Figure 71: Schematic view of a combine harvester header platform, with main components (**A**) crop dividers, on both ends of the header, (**B**) revolving reel to accumulate the grain stalks, (**C**) cutter bar with triangular blades, (**D**) intake auger, (**E**) retractile fingers on the intake auger that guide the material onto the (**F**) feeder belt.

From the feeder belt, the harvested biomass reaches the thresher hub (**H**) where the threshed grain falls through a concave mesh on the lower transport belt to reach two sieves that further separate the grain from husks and other small plant material by oscillating while air is blown from under, produced by the ventilator (**G**), before it reaches the connector tube to the storage container (**I**). Unclean material from under the sieves is transported back to the thresher hub (**H**), and the process repeats. Heavy straw material, including the empty stalks, are taken directly from the thresher hub onto the straw extractors (**F**) to be removed at the back of the machine, together with the finer material that is blown from the grains below. Both systems perform winnowing activities simultaneously to ensure a maximum amount of grains can be recovered as the plant material makes its way through. The complete passage of the grain is shown in Figure 72 to indicate the internal movement of the different harvested plant components.

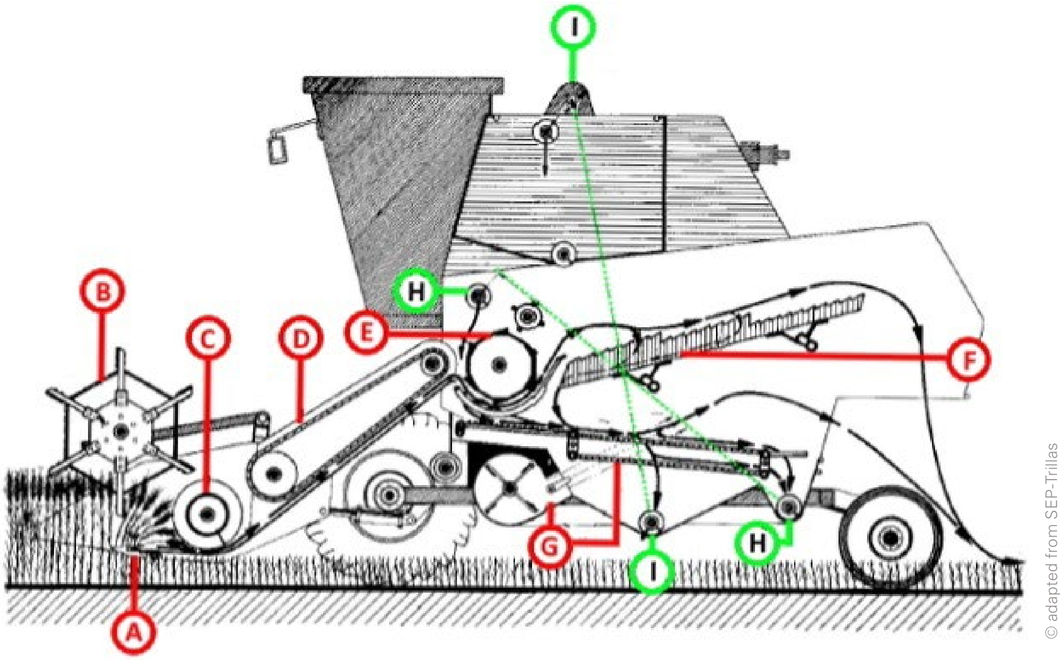

Figure 72: Flow of the harvested plant material through a combine harvester, starting at the (**A**) header platform of the combine harvester with (**B**) revolving reel and (**C**) intake auger pushing the harvested biomass onto the (**D**) feeder belt, into the (**E**) thresher drum. At this point, loosened grain will fall through the bottom thresher mesh on two different oscillating sieves that further remove fine straw material. Clean grain is collected at (**I**) and moved to the storage container, while plant material that remains unthreshed is transported back to the thresher drum at (**H**). Husks and other fine straw material are blown out of the machine by (**G**) the ventilator fan. Rougher plant material reaches (**F**) the straw extractor grids after threshing, which winnow the grain from the residues, with the latter removed from the machine and the grain falling to (**I**).

Session 3.2
Postharvest equipment

Whether harvested manually or with the help of harvesting implements or machinery, in most cases, the harvested material still has to undergo an additional handling process. Depending on the local harvesting conditions, often grain crops still need to be dried, threshed, shelled or milled, or a combination of these to make them ready for consumption or commercialization. All these steps have to be performed correctly, aiming to minimize losses and damage to the grain before, during and after storage to maximize production returns. Many of the operations are performed on the edge of the field or at the homestead or milling area and can be done by an implement that is either stationary or mobile, depending on local availability. Mobile equipment facilitates service providers to go out near harvested fields or directly to the farmers' homes as a fee-for-service income activity, while stationary equipment can often handle slightly larger volumes or serves its purpose as a day-to-day farm aid tool. An overview of the more commonly found equipment is given in what follows[4].

A. Threshers, shellers & mills

Threshing and shelling

Threshing (or shelling for maize) refers to the process of separating the edible part or the grain from the straw or stalk (or cob for maize) it is attached to and is often performed directly after reaping or cutting the stalks from the field. Threshing is done by beating or crushing the tillers of the harvested plant materials. When performed manually, it requires a large amount of physical labour and time and often involves a risk of scattering losses and damage to the crops due to the unsystematic stomping or beating on a floor. Good threshing machines can separate the grain from the straw material, causing minimal damage, and present clean grain at one side of the machine to facilitate recollection. Often motorized threshers even include an air-blowing fan which replaces the need for winnowing and ensures the grains are clean and ready for storage. Many models are available nowadays, including threshers operated by means of petrol, diesel or even electrical engines (Figure 73 and Figure 74).

4 Once more, most attached equipment is either self-powered or driven through a connection with a v-belt or drive train transferring power from an engine block, as described in Module 1. Hence, it is important to make sure belt and chain connections are made properly and care is given to correctly identify clutch levers and disengagement before starting up the engines. If electrical engines are present, make sure to locate the emergency kill switch or be within reach to disconnect the equipment from the power grid in case of emergency. NEVER operate threshers, shellers or mills without the protective lids, with internal parts exposed or with the outlets obstructed.

Figure 73: Different thresher machinery, with (**A**) tractor-pulled mobile thresher trailer, (**B**) two-wheel tractor powered rice thresher, (**C**) a human-powered pedal thresher, (**D**) a two-wheel trailed thresher and (**E**) a self-propelled pushcart model.

To make the right choice of machine, it is important to consider the volume of grain that needs to be processed, the time available, and its final purpose – whether it is for temporal storage before commercialization, long-term food supply or immediate consumption. Fossil fuel engines facilitate mobile rigs or even threshing trailers that can be hauled by tractors. In contrast, electric engines offer a cheap alternative for stationary use, although they often lack the ability to adjust operating speed which might result in more broken grains if not monitored. Important in selecting the equipment is to review how efficiently the grains are separated from the straw material and to check whether the meshed plate under the thresher cylinder has an appropriate diametre for the grains and if the scattering of grains can be controlled. Some recommendations to ensure the right choice of equipment are given.

Figure 74: Manual maize table sheller (**A**), electric single cob maize sheller (**B**), petrol engine dual cob maize sheller (**C**) and a diesel-engine powered maize sheller trailer (**D**).

Steps to evaluate thresher capacity and efficiency

Not a single threshing machine or implement will produce perfect results. However, one can quickly compare different models by reviewing their work capacity and efficiency. The work capacity of a thresher is determined by the amount of grain (g) obtained in a certain amount of time (t), while the efficiency is determined by measuring the difference between the grain weight from handpicking with the grain weight from the threshing machine. Both calculations are explained below.

Work Capacity

1. Depending on the amount of scatter, one could account for all the grains by placing a tarp under and around the thresher or only consider the grain coming from the threshing implement's main exit (which likely reduces capacity greatly).
2. Run the machine for a minimum of ten minutes, feeding the straw stalks at a constant pace.
3. After ten minutes, place the tarp and collecting container where grain is released from the machine and collect the grain by operating the machine for another 15 minutes.
4. After 15 minutes, turn off the machine and let it idle for two minutes without removing the tarp.
5. Stop the machine, gather all the threshed grain and weigh their mass.
6. The thresher work capacity can be calculated as such:

$$Work\ capacity\ (g/h) = \frac{\text{Total grain weight (g)}}{\text{Operating sampling time (0.25 h)} \times 4}$$

Efficiency

1. Take three bundles of non-threshed, recently harvested material.
2. Bundle per bundle, remove by hand all the grain by beating them into a closed container (like a plastic or steel can) until all tillers are completely empty.
3. Weigh the mass of the cleaned grains on a scale and write down the result.
4. Take another three bundles on non-threshed, recently harvested material.
5. Feed these, bundle by bundle, into the thresher machine.
6. Collect all the grains from all the exits and clean out the machine thoroughly.
7. Weigh the mass of the collected threshed grains on a scale and write down the result.
8. Calculate the efficiency ratio as follows:

$$Work\ Efficiency = \frac{\text{Machine thresher grain weight (g)}}{\text{Handpicked grain weight (g)}}$$

9. The closer this ratio is to 1, the better the threshers' efficiency. It is highly unlikely, though, to reach a ratio of 1, since grain dispersion with motorized equipment is difficult to control, and not all tillers will be threshed at 100 percent.

Steps to evaluate the threshing quality

Especially for grain crops that are threshed for storage, it is important that the grains showcase the slightest damage. Cracks and broken grains allow for easy propagation of mould and fungi during storage, and the more damaged grains are present, the shorter the storage life of the final grain. For the same reason, high amounts of visually damaged grains after threshing will also have a lower selling value. Hence, a thresher must minimize damage to the grain. If the thresher produces severe damage to the grain, it might be because the grain kernels were not dry enough before starting the process. A simple method to evaluate this for a thresher is as follows:

1. Collect all grain from all or main exit from the thresher during a certain period of time.
2. Randomly take three samples of 100 grams each.
3. Visually inspect the grains in these samples one by one, and separate broken or visually cracked grains.
4. Weigh the damaged grains per sample and average the results.
5. Use the following equation to define the percentage of damaged grains with respect to the total collected grains.

$$Percentage\ of\ damaged\ grains\ (\%) = \frac{\text{Averaged damaged grain weight (g)}}{\text{Total sample weight } (g)} \times 100$$

Milling

In terms of preparing the harvested crops for food, milling is the logical next step in the postharvest handling of cereals and grains. Particularly for rice, the milling process aims to remove the husk and the bran from the edible part of the rice kernel, known as the two-pass milling process[5]. Milling machinery performs these processes either separately (two-staged) or combined in one machine, where first the husk is removed using rubber rollers, and then the rice kernel is polished by applying friction to the brown rice kernel to remove the bran (Figure 75).

For maize, milling is a slightly simpler process, and a variety of mills are available producing flour of varying coarseness. Milled maize can be consumed as grits or porridge or used as flour base for flatbreads or tortillas (after nixtamalization-soaking in limed water to soften the pericarp of maize grains). Many simple hammer mills can be attached to small engines or 2WT, as shown in Figure 76.

5 Older single-pass rice mills are largely replaced by these newer models, mainly due to high production losses caused by the breaking of more than 50 percent of the rice kernels. Their use is therefore highly discouraged.

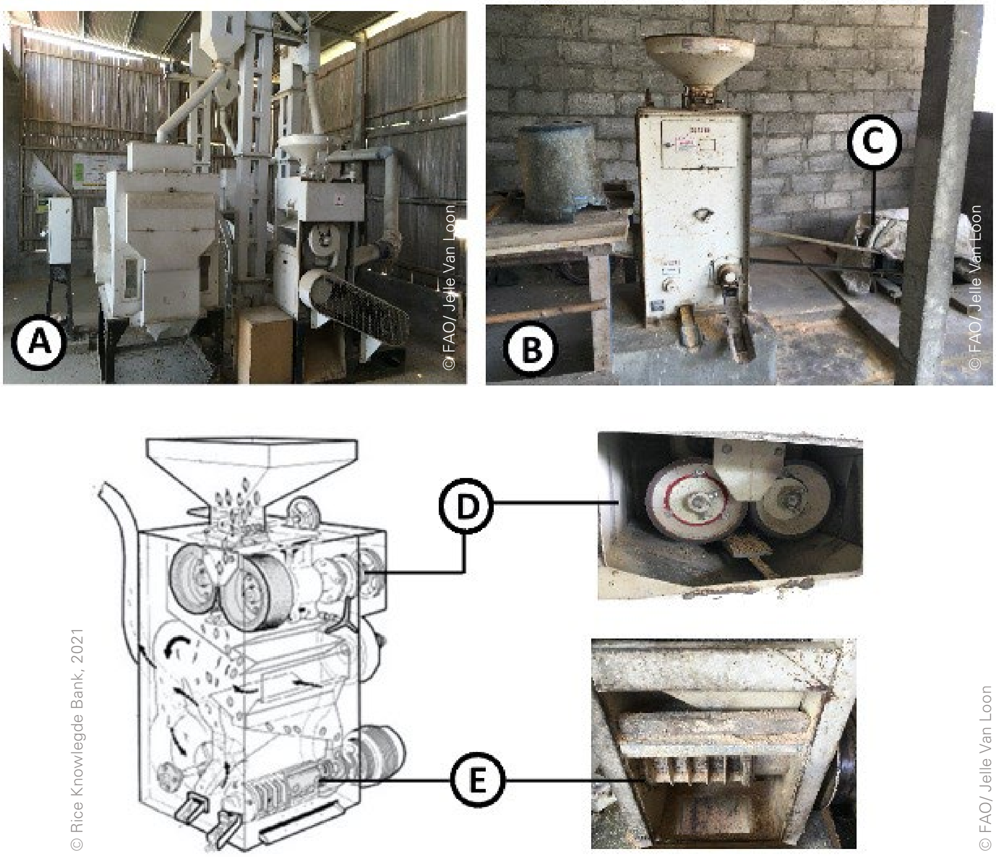

Figure 75: Two-pass rice mills, with a (**A**) two-staged large volume mill in the upper left, a (**B**) single or combine two-pass rice mills powered by a (**C**) diesel engine tractor block, and a schematic overview on the bottom left (adapted from Rice Knowledge Bank, 2021) with (**D**) the rubber rollers for de-husking of the rice, positioned above the (**E**) cylindrical frictioner whitener/polisher that eliminates the bran for the rice kernels.

Figure 76: Overview of hammer-type maize mills (upper left), with an electric engine in the upper centre, an inside view on the upper right and below, attached to and powered by a two-wheel tractor at a farmers' homestead.

Cleaning

As with all machines and farm equipment, proper cleaning and inspection after each use are essential as this will ensure the machine's longevity and will reduce future problems. By doing so, one is more likely to detect structural issues and take preventative maintenance measures. Further, concerns over the presence of mycotoxins and the risk of cross-contamination in threshers, shellers and mills require thorough cleaning after each use and in between grain batches. For this reason, one must make sure that all parts and internal mechanisms are dusted, preferably with compressed air, washed thoroughly with water (or bleach if possible), and left to dry.

What are mycotoxins?

Mycotoxins are substances produced by fungi and moulds that can be found on grain and legume crops as early as when the crop reaches maturity stages. If not adequately addressed and monitored, they can propagate in the grain during harvest and post-harvest handling. Mycotoxins, like aflatoxins, are harmful to human- and animal health and are potentially fatal, causing a series of illnesses such as acute intoxication and cancer. Although most mould and fungi infestation on grains are visible and usually discarded by farmers, mycotoxins – as secondary metabolites of these moulds – are often not visible with the naked eye and can be transmitted by contact and may remain present on the pericarp of healthy grains. High humidity in grains (> 14 percent) and insects that feed on the grain during storage can subsequently weaken or intrude the pericarp and allow further infestation.

Therefore, fast recollection and drying of grains before storage, ensuring a minimal amount of grains are damaged during threshing and shelling, and proper cleaning of any equipment used in grain processing are critical.

A quick tip to know whether grains are sufficiently dried before processing is by placing them in a sealed glass container in the sun. If, after 10–15 minutes, little droplets of condensation have formed on the inside of the glass wall of the container, the grains still require more time to dry properly. This can be done by industrial machines or on well-aerated platforms elevated from the ground.

Source: Golob, P. 2007. On-arm mycotoxin control in food and feed grain. Good Practices for animal feed and livestock. Rome, FAO. fao.org/3/a1416e/a1416e00.pdf

B. Storage technologies

When storing grain, threshed or un-threshed, it is of utmost importance to keep the area clean and dry. Therefore, grains should be stored in sealed containers or, if not in containers, on a platform elevated from the ground to avoid ground humidity and limit mould and fungi propagation. In addition, one must pay close attention to restricting access of insects and pests like rodents to the grain as these will consume part of the grain and reduce the storage life by damaging and soiling the storage area.

Jute, sisal or polypropylene bags are often used to store grains, but these are penetrable by rodents and are not an adequate barrier for insects. To solve the latter problem, grains can be mixed with dilute insecticide dust (Actellic 2 percent) before being placed in the bags (Golob, P.

2007) Contrastingly, keeping rodents away from the grain is far more challenging but could be achieved by using cylinder-shaped metal silos.

Ideally, hermetic technologies should be used to store grain long-term, especially since oxygen availability in non-hermetic solutions provides an opportunity for all living organisms to survive inside and proliferate, consuming the stored grain. Hermetic metal silos are constructed so that no air exchange from the exterior to the interior or vice versa can occur once closed (Figure 77). By keeping the silos sealed off for a minimum of three months, all present insects die off after consuming the remaining oxygen and mould infestation comes to a halt. Besides sealed metal silos, other hermetic technologies are available, including polyethylene bags as a cheap alternative. In this case, to increase durability, jute or woven polypropylene bags can be lined with these hermetic bags on the inside to give extra protection (Figure 77). When closing the bags, it is essential to make the seal airtight.

Some useful resources include:

- Technical manual for the construction and use of family-sized metal silos to store cereals and grain legumes
- Household metal silos key allies in FAO's fight against hunger

Figure 77: Postharvest technologies for storage of threshed grains, with regular metallic silos in the upper left, and hermetic silos on the upper right, polyethylene plastic bags below, with binding for hermetic sealing and placed into a jute bag to increase durability.

C. Repairment of pushcart thresher

Exercise: Step-by-step review, maintenance and repair of pushcart rice/wheat thresher
In this segment, a more practical approach will be taken to explain the components and functioning of a standard pushcart multi-crop thresher. The idea of this segment is to give a structural overview of a commonly found mobile machine used in smallholder contexts for threshing recently harvested bundles of rice or wheat stalks, and which can be powered by any light engine, either through a v-belt connection attached to a two-wheel tractor or directly with diesel, petrol or electrical engine block mounted on the cart's frame. Parts and internal components will be reviewed and briefly discussed, focusing on how they all fit and work together. Therefore, this text will provide a reference guideline for assembly/disassembly of similar thresher carts and facilitate repairs.

Main components and functioning

The pushcart thresher model presented here is a standard mobile pushcart that can thresh several cereal crops, including rice, wheat and barley. The thresher is powered by a 9hp diesel engine, identical to the ones used on the heavier-type 2WTs. The main components can be seen in Figure 78, with the main lid and feed table on top (**D**), which houses the thresher drum (**G**) and sieving mesh (**F**). Stalks are removed through the outlet funnel (**L**). The thresher cylinder is actuated through the pulley and v-belt system (**C**) from the engine block. Once passing through the thresher drum, fine straw material and grains drop inside the cart, where a ventilator fan (**J**) blows out all the remaining straw bits through the outlet drawer (**K**). Finally, grains are collected at the bottom of the cart, at the principal grain exit (**I**). The cart can be transported as a wheelbarrow carriage using the handlebars (**H**). Figure 79 shows the flow of the grains and discarded straw material through the machine.

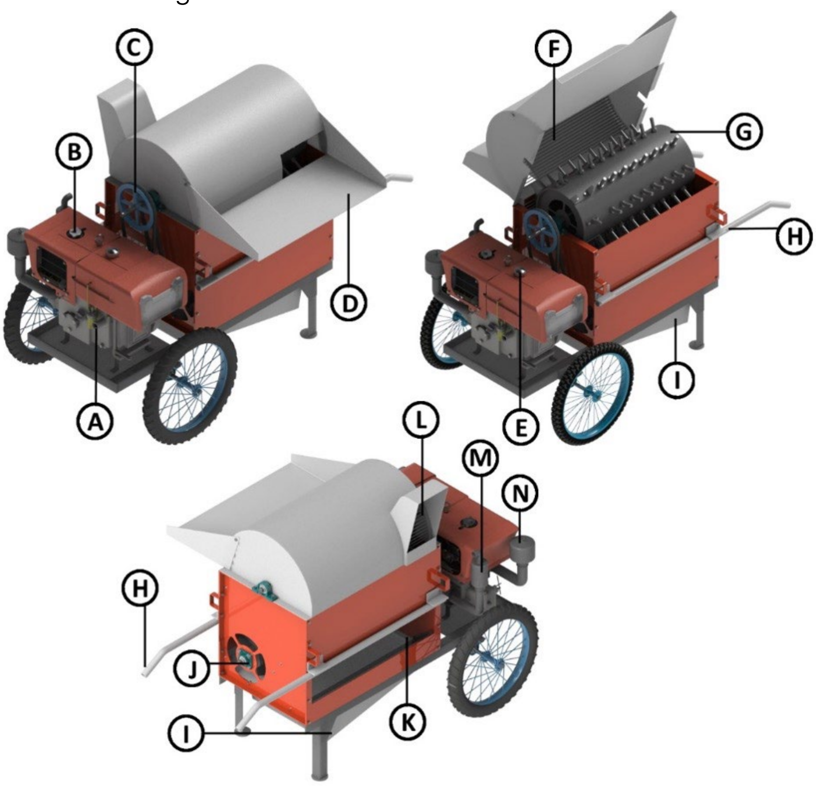

Figure 78: A diesel engine powered pushcart thresher model with main components, including (A) crank starter plug to activate the engine, (B) engine radiator cap, (C) thresher pulley and v-belt connection to the engine's flywheel, (D) feed table to insert harvested material, (E) engine fuel cap, (F) thresher lid with mesh, (G) threshing cylinder, (H) handle bars, (I) principal grain exit, (J) ventilator blower fan, (K) husk and straw outlet drawer, (L) principal straw outlet funnel, (M) engine exhaust and (N) air filter housing.

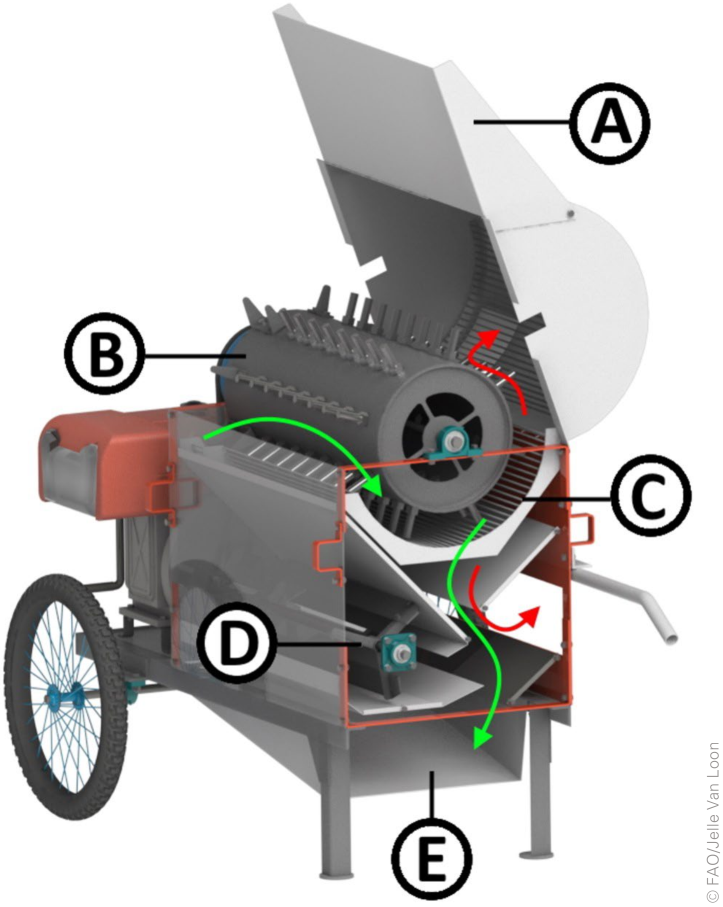

Figure 79: Internal component of pushcart thresher with a schematic flow of harvested materials (grains – green, straw – red), entering from the (A) feed table into the thresher drum with (B) threshing cylinder and (C) separating mesh. Rough straw material leaves the drum after a passage through the primary straw outlet funnel (not shown). Finer material passes through the thresher mesh, with grain dropping downwards to the principal grain exit (E), while husks and other fine straw material is blown out towards the outlet drawer (not shown) by the air produced by the (D) ventilator fan.

Assembly and configurations

The pushcart thresher excels due to its simplicity in setup (Figure 80) and ability to process a decent volume of harvested bundles of grain stalks in a short amount of time and with minimal fuel and effort. It is always best to first test the machine with a small amount of material, adjust engine (or rotational) speed, and possibly install the appropriate threshing teeth on the thresher cylinder and adjust the sieving mesh beneath according to grain size (Figure 81).

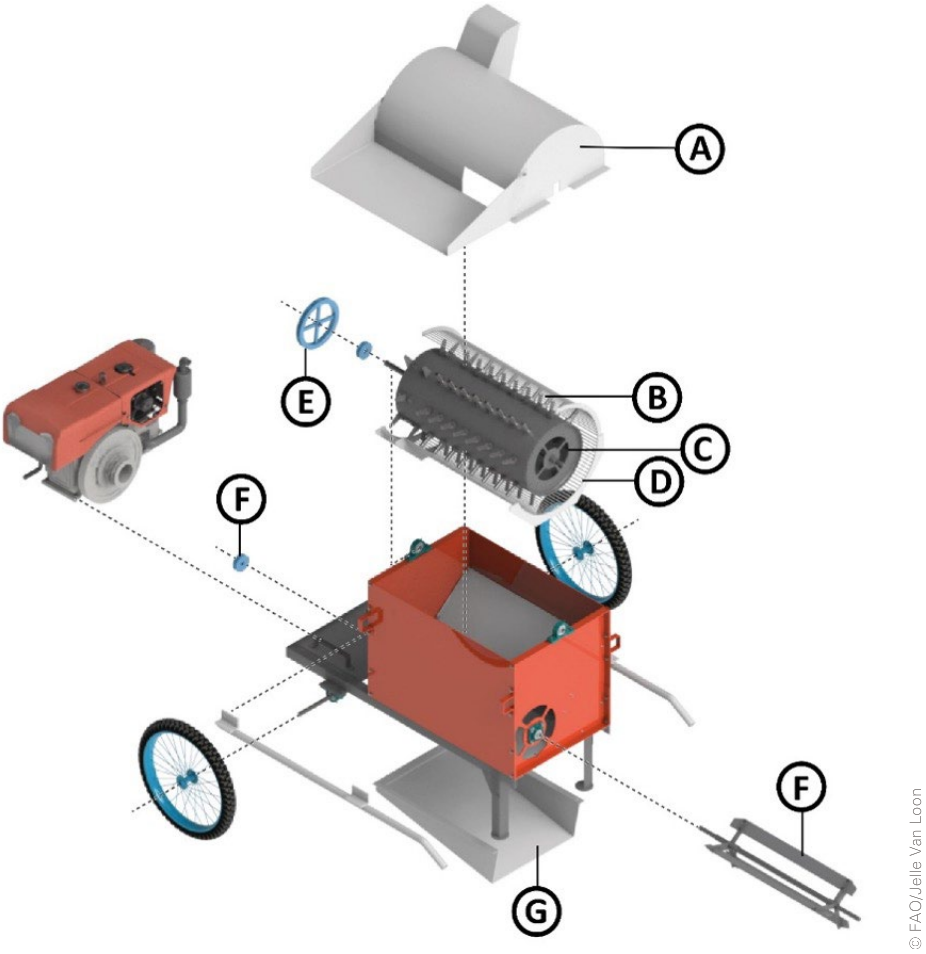

Figure 80: Exploded view of a pushcart thresher for assembly purposes, with (A) thresher lid, the thresher drum with (B) upper mesh, (C) thresher cylinder, (D) lower mesh and (E) pulley and bearing on located on the main driving axle; ventilator or blower fan (F).

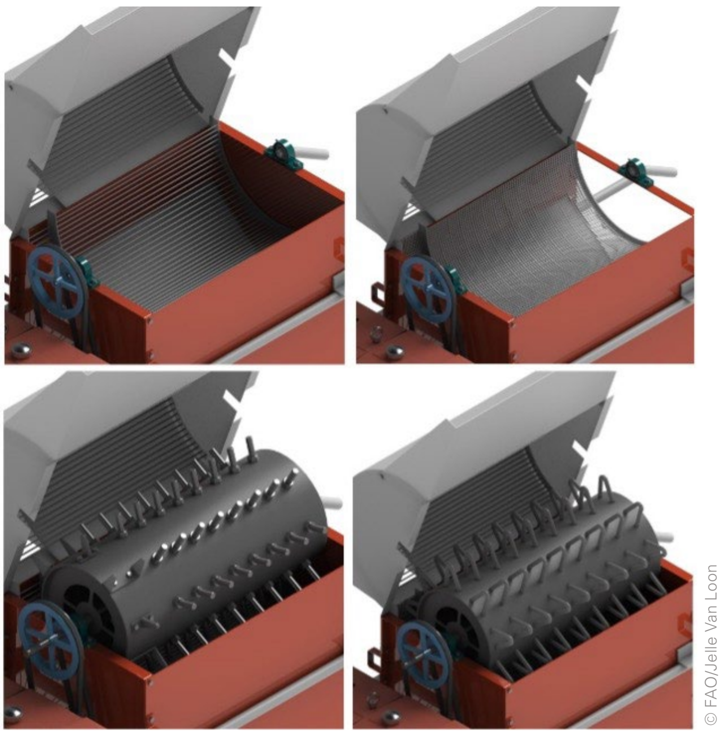

Figure 81: Configurations for the thresher drum on a pushcart thresher, with the standard sieving mesh (upper left) and a second mesh for different sized grains (upper right), and with the standard threshing cylinder with bolted teeth (lower left) or with bended hooks (lower right) for smoother and less abrasive action.

Moving components and troubleshooting

The thresher is a machine with many moving parts, and the heavy workload can strain these components. It is essential to always keep all bearings in good condition and properly lubricated. Make sure to avoid small gravel or pebbles that may get stuck to the harvested material, and remove pebbles from the sieving mesh if found. Because of the moving parts, the handler should always be alert during operation as these parts pose a risk for limbs or fingers, especially at the feed table. Additionally, always make sure the machine is turned off and wait until the moving parts come to a rest before opening the lid for adjustments or when cleaning out the grain from the bottom.

Troubleshooting

Whenever the thresher is visibly struggling, producing unexpected sounds or not properly working, stop the machine immediately and review these troubleshooting tips to solve the most common problems.

- A lot of unthreshed material comes out of the outlet funnel and/or drawer.
  - Decrease the thresher's rotational speed.
- A lot of impurities and fine straw material is found in the principal grain exit.
  - Increase the thresher's rotational speed.
- The thresher suddenly stops working, but the engine is still active.
  - The v-belt loosened, turn off the engine and put it on again or replace if damaged.
- Much of the grain sticks to the internal sides of the thresher, and grains do not separate from the straw material easily.
  - The harvested material is still too wet, make sure it is dried properly before threshing.
- The thresher drum is not turning properly, although the engine is exerting its full force.
  - Too much material is fed to the machine at the same time, stop, clean and start again feeding material at a slower pace.
- During operating, the thresher makes an unexpected, clangy sound.
  - Likely some rocks got into the thresher drum. Turn the engine and clean out the machine before starting again.
- The engine was working properly, but now won't start again.
  - Check the fuel level and refill if empty, check fuel lines for bends that obstruct proper flow.
- During operation, the thresher makes an unexpected, screeching sound.
  - Some metal internal parts are likely broken. Stop the engine, clean out and repair the part.

As a reminder, it is vital to clean the thresher properly after each use and in between crop batches to ensure the machine's longevity and to minimize the risk of mycotoxin cross-contamination. Dust off all parts, clean out the equipment with water and possibly bleach, and dry quickly. Review any imperfections, put primer of chipped paint to avoid oxidation, tighten bolts and fix possible cracks in welding.

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Module 4

Additional information

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Session 4.1
Maintenance, spare parts and replacements

During field operations, farm machinery is exposed to rough conditions and suffers continuous wear and tear, often resulting in the equipment's damage and downtime. Machinery that is not maintained properly will suffer more frequent breakdowns than those taken care of regularly. This caretaking includes cleaning up the machine after use, placing it in a litter-free place out of harm's way and covering it with a tarp to avoid deterioration by the weather elements.

Preventive maintenance in this sense should be done after the cleaning and before putting the equipment to rest after field activity. It includes a visual inspection of the main operating components of the machine and replacing parts that are at the point of being worn out. The parts that require special attention are implements that directly engage with the soil or crop (tips of ridgers, discs and tines, etc.) and moving elements (chains, sprockets and bearing, seed and fertilizer metres, cutting knives, etc.). Ensuring a minimal inventory of spare parts and the ability to replace the most critical and common parts in a timely fashion can resolve a great deal of problems in the long run. Therefore, it is important to review the availability of spare parts with the machine providers upon purchase and to make sure you have a stock of at least one of each at your disposal. If it is not possible to build up a stock, it is always wise to write down the number, type, name, model and make of the part so dealers can easily find the right piece or at least compare for compatibility with others. In addition, machine distributors often can provide exploded views for assembly/disassembly or, for the more common replacements jobs, tutorials can be found on the internet. In general, do not start a job that cannot be finished in a short lapse of time. Preparing all materials needed and give yourself enough time to avoid rushing. This way, you will avoid losing parts and forgetting them during the assembly process.

General considerations when replacing a component with a spare part

1. Double-check whether the problem is actually solved by changing this part.
   - In case the part is stuck, it might be because of dirt accumulation.
     - Make sure to clean all crevices or nooks of the component; applying compressed air when everything appears clean can help.
   - In case a bearing is stuck, a lack of lubrication might be the cause of the problem.
     - Generously apply WD-40 multipurpose oil and try to get the part into movement after 5–10 minutes.
2. Make sure all surrounding parts are clean and that you correctly understand the component's location, position and function before disassembly.
   - Tracing and manually moving all involved parts can help to understand this.
   - Taking photos of the original position and configuration to compare afterwards is always a good idea.
3. Loosen all belts, cables and chains on the main mechanism.
   - Tagging these connections with a permanent marker and a cellophane tape will help you keep track.

4. Start by unscrewing all visible screws, nuts and bolts.
    - Put them in transparent plastic bags for safekeeping until re-assembly, tagging each set of screws per sub-component or layer.
    - In the case of nuts and bolts, keep them together with all rings or spacers that you remove.
5. Carefully remove parts in an orderly fashion and number them to remember to place them back in the reverse order when re-assembling.
6. Take out the part you wish to replace and double-check whether the replacement part is identical/compatible.
7. Put the replacement part in position and, if applicable, check correct rotation or movement when possible.
8. Place back all other components in the reverse order as disassembled.
9. Re-assemble all screws, nuts and bolts with corresponding rings and spacers.
    - If at some point you see you forget some, stop and redo before continuing. It might be important to ensure a correct and snug fit of all other pieces.
10. Before reconnecting all belts and chains, manually move the assembled parts to check the correct operation.
11. Reconnect all belts and chains, matching the photos taken beforehand.
12. When finished, carefully start up the machine and test the proper functioning.
    - Where possible, first try at slow speed before putting the machine into full power.
    - At first instant at start-up, keep a certain distance to avoid hurting yourself in case something goes wrong.

If no spare part is available immediately, the part might be manufactured by a local workshop or blacksmith, especially for metal components. In this case, take a picture of the component before disassembling it and review it with the workshop if it can be done. Plastic components might also be manufactured locally from nylamid (impact modified nylon compound which is good for bearings and other parts that receive a lot of friction) or temporarily be preplaced with a hardwood replicate (this could be a quick fix especially for seed plates, rollers and tensioners).

Tips for replicating a spare part with the help of a workshop

1. Check whether technical drawings are available on the internet of the particular part that needs replacement.
2. Isolate the particular part and make sure to write down all dimensions, including the thickness of the piece.
   - Tracing on a piece of paper from all sides and writing down exact measurements can be quite helpful to make sure holes and perforations are positioned correctly.
3. If possible, bring the piece to the workshop and see if it can be fixed by welding, gluing or other means before discarding.
4. Make sure to explain to the workshop what work the part is used for and discuss the material strength needed.

In many cases, most parts and components of a machine, or even an entire farm implement, can be (re)built in a local workshop. For certain models, full construction plans are also available. When technical drawings are available, they are often structured in an organized way so that parts and pieces can be identified according to the main components they belong to. With some help from an experienced local engineering shop or metal workshop, components can be replicated using the right material. When manufacturing a component from scratch, some deviations in dimensions and materials are allowed, so long as they do not hinder the machine's operability, and the manufacturer considers the machine's use, amount of pressure, and friction the parts will undergo. These measures will ensure the retention of the machine's function, robustness and integrity.

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