# Chapter 10

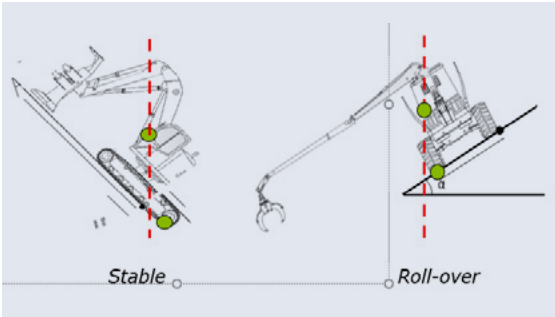
## Stability and traction

# In this chapter you will find out:

- ✓ How gravity changes stability.
- ✓ Things to watch out for that affect machine stability.
- ✓ How traction changes with slope and soil conditions.
- ✓ Why a winch improves traction.

## Stability

Stability measures how likely it is for an object to roll-over when pushed or moved. Stable objects are difficult to fall over, while unstable objects topple over very easily. A machine rolls over when they are out of balance. That's technically when the centre of gravity is 'outside' the base, or edge, on which it balances.




Machines rarely just fall over, and an operator can often act to stabilise the machine. The risk of a rollover increases on slopes of more than 50% (28 degrees).

Beware of SLIP-SLIDE-TIP.

## What affects stability

A loss of traction is the most significant cause of a loss of stability. Any factors that reduce traction efficiency impact traction. Refer to the 'what affects traction' section.

- Most rollover accidents are caused by loss of traction. The steep slope harvesting machine begins to slide, and then the tracks/wheels hit an object like a stump, log or rock. This leads to a change in stability and rollover.
- A change in slope can also affect stability because the machine's weight and centre of gravity may change rapidly, e.g. dropping off the road near the anchor onto the felling area.
- The machine type and where the load's position influences stability too.

Loss of traction causes most rollover accidents.

# Traction

Traction is the 'grip' the machine has on the slope. The primary purpose of the winch-assist is to help improve traction. Maintaining traction is essential to control the machine's stability.

The section explains what affects traction and explains in detail how soil strength, slope steepness and the cable itself can affect a machine's ability to climb.

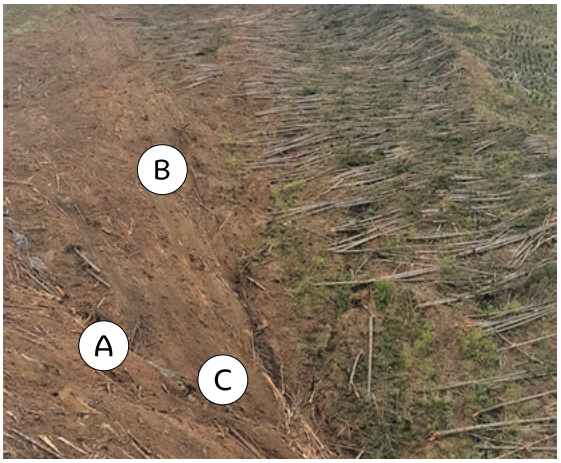
## What affects traction

Traction constantly changes. Four main factors can affect traction. Some of these can combine to either make traction significantly better or worse. Two factors we can't change, and these are the:

- Harvest area's site considerations like the soils, geology, slope, aspect, windthrow, and terrain features.
- Environmental factors like rainfall, sunshine, wind, fog or darkness.

The other two factors the contractor and operator have some influence over and can adjust or modify. These are the:

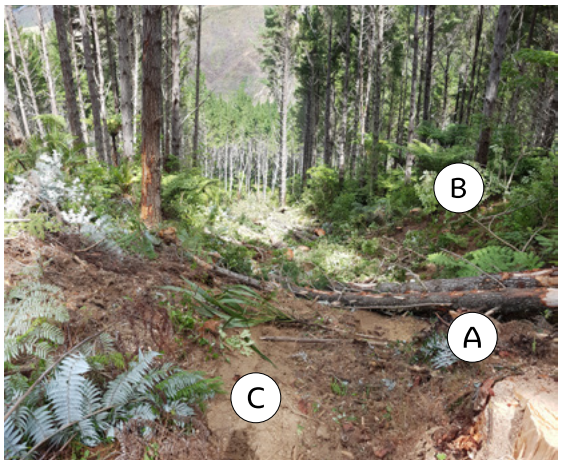
- Machine, e.g. type and weight, grouser size, machine limitations, and maintenance.
- Operator experience and care, e.g. amount of tension applied by the winch through the cable.




A Terrain – boulders, rock, thin soils and gullies

B Wet locations – aspects that get less drying, or poorly drained soils

C Steep slopes especially over 35% (20 degrees), and long steeper slopes




A Windthrow, stumps, and woody debris
B Dense scrub that obscures a ground view
C Soil like clay or black soil, that are worse when wet

Also:
- Strong winds and poor visibility
- Heavy rainfall, or increasingly wet weather conditions

Common natural hazards are stumps, holes, rocks, drop-offs, windthrow and thick scrub.

## Loss of traction

Slipping indicates the tracks are losing traction. Slipping reduces soil strength because the tracks cut through the slash and vegetation that help support the machine. During high slip, the spaces between grousers can become packed with soil, and they stop biting into the ground. Machines can slide even on moderate slopes of 30-40% (17-22 degrees).

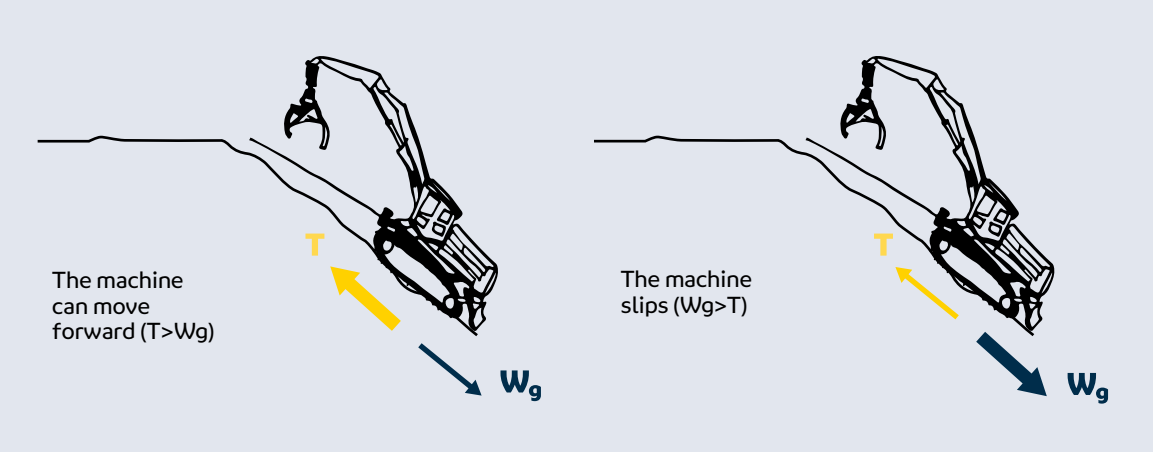
Loss of traction can lead to machine rollover.

## Why traction changes with slope

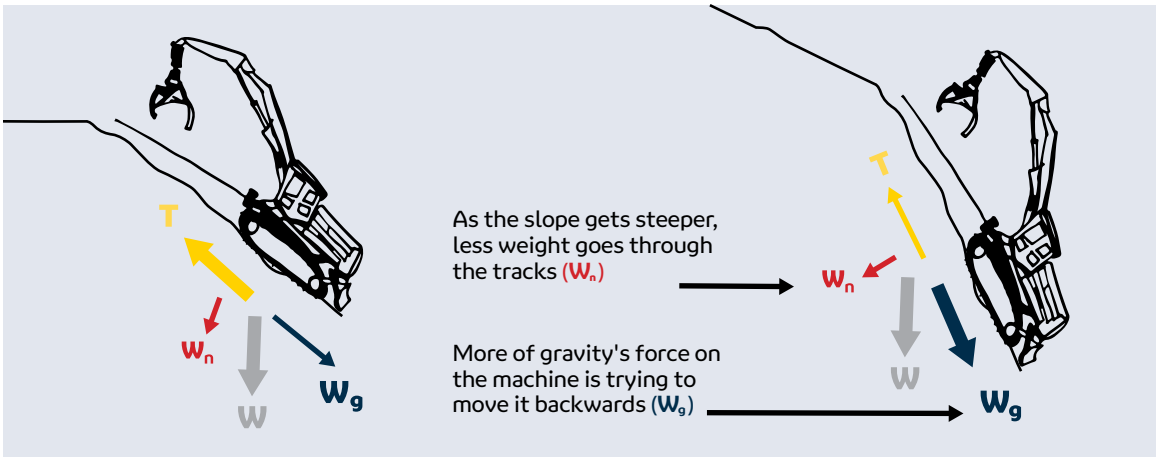
Slope affects traction. As the slope increases, the machine's tracks are more likely to slip.

This is because the steep slope harvesting machine must fight gravity to climb. Gravity is trying to slide it down the slope.

1. Traction is lost when the force of gravity (Wg) is greater than the machine's ability to go forward (traction force or T).




2. Traction reduces as slope increases.

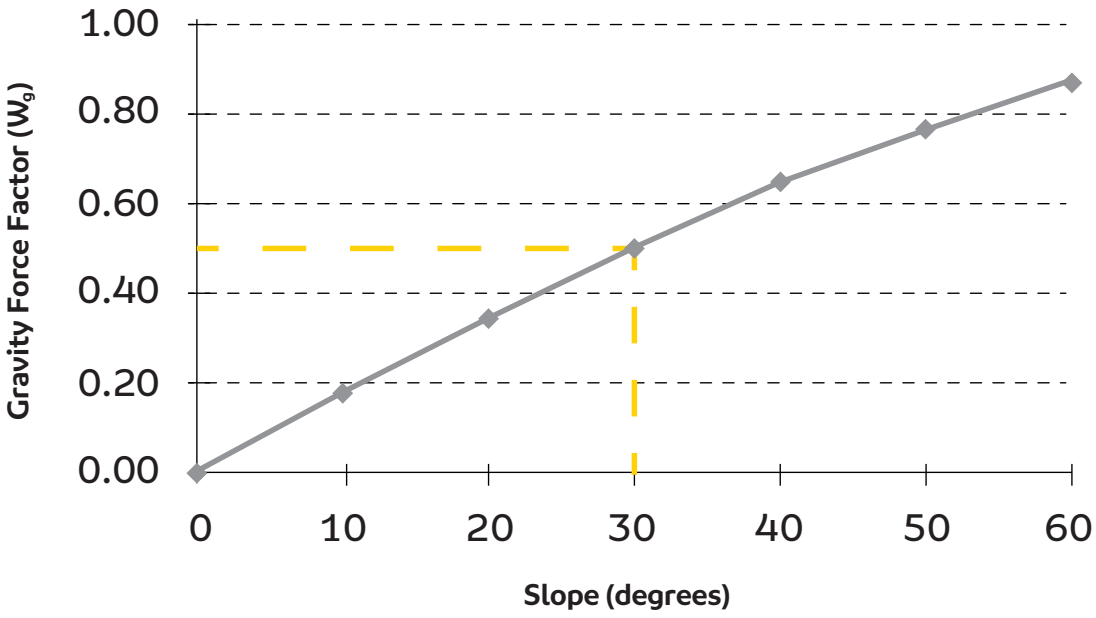


Machines are much less likely to slip on a flatter slope than a steep one, all things being equal. The reason is due to how gravity behaves. On a flat surface, gravity pulls down directly. On a steepening slope, less of gravity's force gets to go directly down through the tracks. The force directed on the tracks is called gravity normal force or $W_n$.

As the slope gets increasingly steeper, less force goes through the tracks ($W_n$), and more force is trying to pull the machine backwards ($W_g$), as seen in the diagram below. The equations are:

**Normal force ($W_n$)** = machine weight x cos (slope angle)

**Gravity's force ($W_g$)** = machine weight x sin (slope angle)




*At 30 degrees, the gravity's pull on the machine is already 50% of the machine weight!*

## How to measure slope

Slope is easier to measure over long distances than short ones. However, the slope immediately around the machine is what's really important to know especially if it is steep. The dominant or long-distance slope gives an indication of overall steepness. A recent study indicated that the machine's slope is often different than the terrain slope.

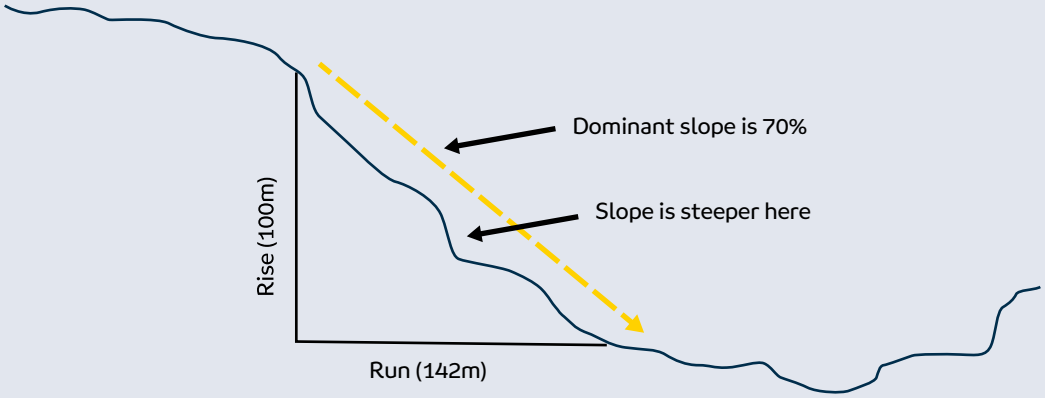
Slope is commonly referred to in two types of measurement units. These are degrees and percent. While degrees are often still used in New Zealand, percent is recognized internationally. See page 100 for degree/percent comparisons.

**Calculating Slope**

Slope can be measured off a contour map:

- It is best to start on a contour and finish on one.
- Measure the ground distance (also called the 'run') between the contours.
- Next count the number of contours (called the 'rise').
- Dividing the rise by the distance will give you the slope in %.

In the following example the map scale was 1:10 000 and the contour interval was 10m. If there were 10 contours crossed the rise, is 100 metres (10 contours multiplied by 10). If the ruler distance was 14.2mm, then this equals 142 metres on the ground. The slope is 100/142 x 100% = 70%.




**Dominant slope = Rise divided by run** **100/142 = 0.7 or 70%** **70% = 35deg**

## How steep is too steep?

Many factors other than slope affect safe machine operations e.g. soil condition, operator skill, the machine, and the roughness of the slope. Operators say productivity drops on slopes greater than 42 degrees.

The following chart gives some indication of boundaries.

| Slope (degrees) | Slope (%) | Consideration |
|---|---|---|
| 17° | 30% | This is considered a limit for when a wheeled ground-based machine can start to slide under poor conditions. |
| 22° | 40% | This is considered a limit for a tracked ground-based machine. It can start to slide under poor conditions. |
| 28° | 50% | Most purpose built forestry machines, with good operators in good conditions can work up to this limit. Beyond this slope it is wise to consider using winch-assist. |
| 35° | 70% | This is considered the absolute upper limit for ground-based machines without winch-assist. Only under very favorable soil strength condition, with a purpose built steep slope harvesting machine and a very experienced operator, and then only traversing directly up or down the slope. |
| 42° | 90% | A realistic upper limit for all winch-assist operations. |
| 45° | 100% | Considered the absolute upper limit for any winch-assist operation. If any part of the rigging fails, a machine roll-over would be difficult to avoid. |

The following table shows that on steep slopes maintaining traction is essential, otherwise the anchor and rigging can carry loadings higher than the SWL of the rope. If the SSH machine slipped and created a shock loading too, then the weight would be much higher.

Traction is lost when the force of gravity ($W_g$) is greater than the machine's ability to go forward (traction force or T).

| Slope (degrees) | Gravity's force trying to pull it backwards (% of machine weight) | Gravity's force trying to pull it backwards (tonnes, on 45t SSH machine) | Winch tension Average operational setting | Tonnes>$W_g$ Good soils 90% Traction efficiency | Tonnes>$W_g$ Poor soils 50% Traction efficiency |
|---|---|---|---|---|---|
| 30° | 50% | 23 | 8 | 19 | 3 |
| 35° | 57% | 26 | 8 | 13 | -1 |
| 40° | 64% | 29 | 8 | 8 | -6 |
| 42° | 67% | 30 | 8 | 6 | -7 |
| 45° | 71% | 32 | 8 | 3 | -10 |
| 50° | 76% | 35 | 8 | -2 | -14 |

*Assumes the machine's weight is 45 tonnes, plus 2 tonnes of working force to shovel or hold a tree, and all other things are constant like the traction efficiency and the soil conditions.*

| | |
|---|---|
| The ability for the machine to go forward **is limited** without addition winch pull (tonnes) | |
| The machine can't move forward and requires additional winch pull (tonnes) | |

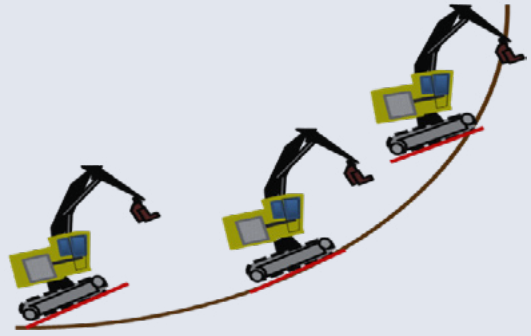
SSH machines must only be operated in locations and with techniques that assure stability.

## The difference between machine slope and terrain slope

The machine's angle or steepness can be different from the terrain steepness. The main reasons are the resolution in the terrain slope data and the operator's skill. Even with LiDAR slope maps, each pixel, or smallest coloured square, maybe 10m x 10m. A machine's track base is much less than a pixel or the dominant slope. Good operators on steep terrain manage slope by using minor slope changes like flatter areas for the machine.

The University of Canterbury studied 22 machines during normal steep-terrain operations and recorded both terrain and machine slope:

- Terrain and machine slope are nearly always different.
- Machine slope was higher than terrain slope except for steep sites.
- On steep slopes, machine slope was less due to operator management.



Machine slope can rapidly change on broken ground. Watch for holes, drop-offs, and old tracks.

## Why traction changes with soil strength

Understanding soil strength is important because it affects traction and stability. Weak soils can make working on flatter terrain tough going, yet strong soils on steep terrain can work well. Regularly evaluate soil and its ability to provide good traction.

Saturated soils are very weak.

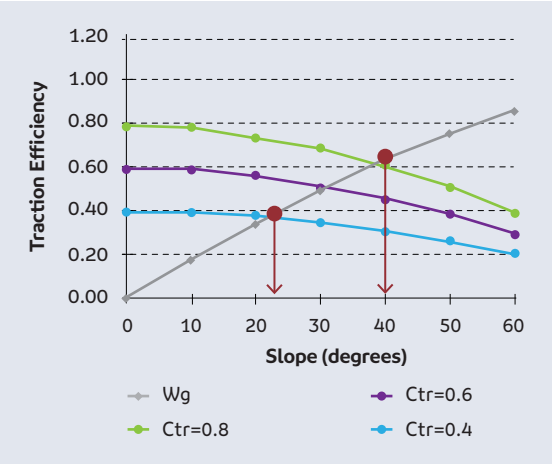
Strength varies between different soils.

Even the same soil's strength changes depending on wetness.

**How do you know the strength of soil?**
Traction efficiency (CTR) is the interaction between the track type on the soil composition. The following is a guide for traction efficiency:

- **40% – Weak soil =** sandy, loose, or wet soil. They are easy to move with a shovel.
- **60% – Firm soil =** shovel goes in when you use your foot.
- **80% – Strong soil =** tightly bound gravelly soil with clay. Hard for a shovel to go in.

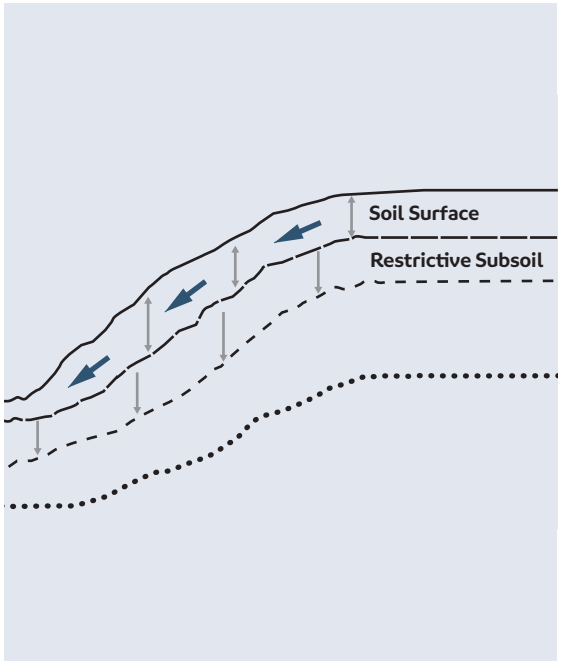
For example, extended grousers can increase the traction efficiency on weak soil as it penetrates further into the ground to increase its holding capacity. Conversely, extended grousers can decrease traction efficiency on strong soils as they ride on the tips of the grousers.




*Poorer traction due to wet or weak soils means machines should only work on less steep terrain.*

Tracked machines typically have a tractive efficiency of between 0.4 and 0.8. The difference in the value depends on the soil and track type. A weaker soil gives the machine less traction before it slips. In the example, it is the difference between working on a slope less than 22 degrees or one of 40 degrees.

Watch for springs or where water runs just below the soil surface. In ash and papa (mudstone) country, water runs where the soil hits the papa rock. This creates a slippery surface called a greasy back.

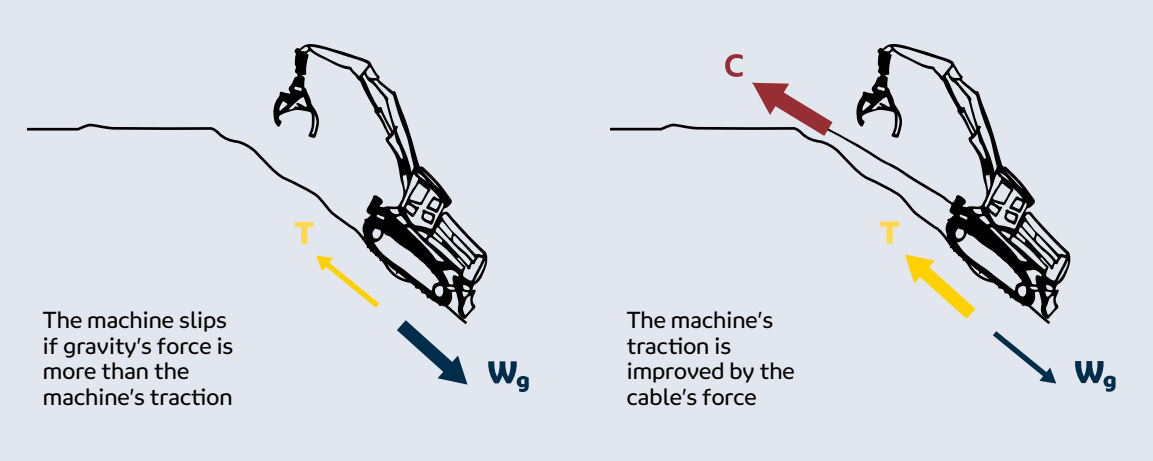



*Left: When water hits a restrictive subsoil (blue arrows), it creates slippery conditions.*
*Right: Track slipping creates safety and environmental concerns.*

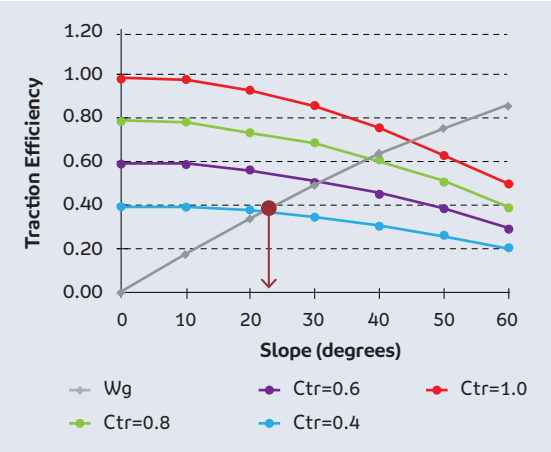
If it is too wet, don't work.

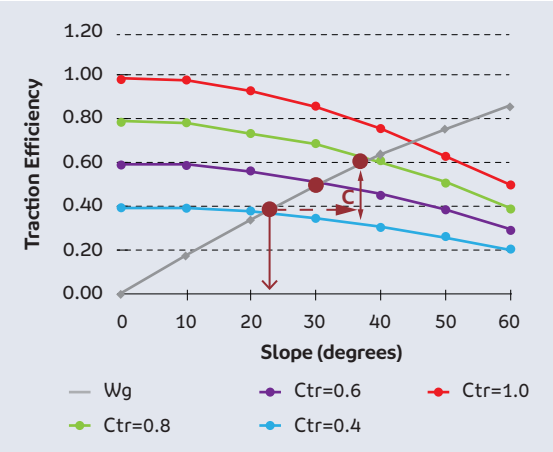
## How traction assist increases slope capability

The force in the cable offsets some of the gravity force acting on the steep slope harvesting machine. Also, a cable better distributes weight on the tracks. This increases traction because it gives additional traction force.




*Left: With no cable tension, if gravity's force on the machine, $W_g$ was greater than the machine's traction, T, then the machine would slip. With cable tension, the machine's traction is improved. This is because of the winch-assist force, C.*




*The graphs above show the effect of cable assistance on the operating slope for a 45 tonne machine.*

*Left: without a cable, on weak soil (0.4) a machine can work up to about 22 degrees.*

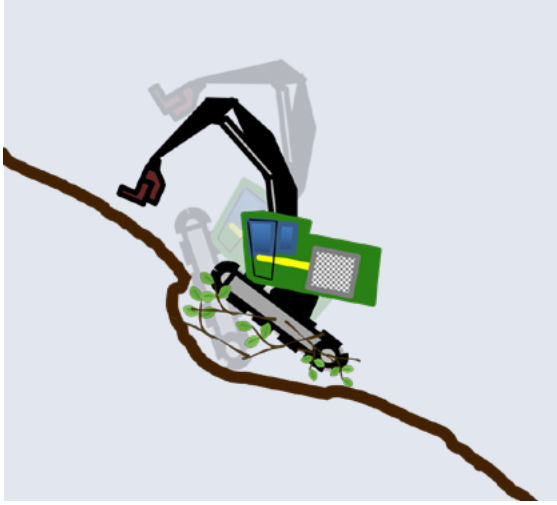
*Right: on the same soils with cable assistance, of approx 8 tonnes, the machine can now retain traction at 31 degrees. With 12 tonnes of assistance, traction is maintained to 36 degrees.*

*Some tables and spreadsheets can help calculate the forces on winch-assisted machines.*

## Why traction increases with a slash mat

Using some slash can increase traction on most soils. This is because slash can help bind the soil and increase its strength. It is good for the environment too, because slash helps reduce wheel rutting, erosion and sediment.

Slash can also be used to fill holes to smooth terrain.



Slash mats can slip on high clays soils.
Larger woody debris can reduce traction through slipping.

# Guidelines to help prevent machine rollover

**Moving – all machine types**


A Only turn around on a steep slope when there's a flat and wide bench

B Cut and move away woody debris that could affect traction and stability

C Keep boom stationary when moving otherwise weight and traction on each track changes

D Keep the saw head or grapple close to the ground to provide quick stability support

E Going over steep terrain lower boom and head and use for stability

F Before moving into the harvest area, pre-tension ropes to immediately support the machine. Check lead angles are OK

G Keep tracks parallel to the slope so the grousers or tyres provide resistance to sliding

Also:

- Avoid terrain that could affect traction and stability.
- Remove dense understory that blocks a clear view of the ground.
- Keep within the lead angle.
- Check rope and connectors are secure and not damaged.

### Felling – all machine types


**A** Work straight up or down the slope, never across it

**B** Cut stumps off low to the ground

**C** Fell, lift, and lay trees that are within safe reach

**D** As slope increases fall narrower strips for machine stability


**A** Make machine stable before swinging wood.

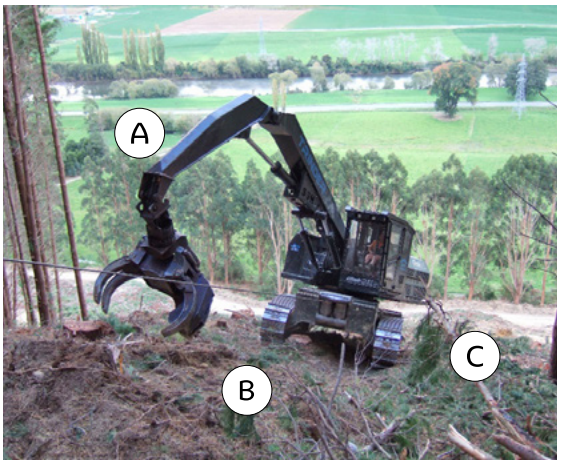
**B** Keep to the machine's cutting diameter and lifting limits.

Also:

- Lift trees no higher than necessary and not more than 3 m.
- Avoid swinging trees to the downhill side of the machine.

- Avoid lifting the boom straight up and tilting trees back over the machine (to the downhill side).
- Position cut timber from 10 o'clock to 2 o'clock when working uphill.
- Face the boom downhill on slopes greater than 30 degrees.
- Use multiple cuts only to fall a tree directionally. The equipment must have sufficient pushing power to direct the tree against its lean. Sufficient holding wood should be maintained until the machine is positioned to make the final cut.

**Tracked machine – moving**




A Ensure the boom is facing the right direction before engaging the winch.

B Keep the tracks parallel to the slope so the grousers provide resistance to sliding.

C Use single bar grousers for the best traction.