Quantifying Ground Disturbance and Soil Compaction After Forest Harvesting

Final Report

for the

Nova Forest Alliance Model Forest

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Introduction

Conservation of soil and water quality is recognized as one of six main criteria for sustainable forest management. One indicator used to evaluate this criterion is the area and percent of forest land with significant soil compaction resulting from human activities.

Compaction damages a soil by reducing porosity (especially macro-porosity) and by damaging soil structure. These changes can negatively impact water flow and air exchange in affected soils, leading to reduced tree growth. All forest soils have the potential to be compacted during harvest or silviculture operations. The question is - how can the risk of compaction be readily assessed on a site, and what level is considered significant and/or acceptable.

A review of literature concerning forest soil compaction indicates that:

- The level of compaction which results from forestry operations is highly variable and depends on such things as (i) soil texture, (ii) soil strength, (iii) coarse fragment content, (iv) forest floor thickness, (v) soil moisture content, (vi) vehicle type and configuration, (vii) the number of vehicle passes, (viii) vehicle loads, (ix) terrain conditions, etc.

- The level of compaction which is significant (with respect to reduced site quality) is site specific. The same relative level of compaction can result in severe, moderate, negligible, or even positive impacts, depending on soil and site conditions.

- Where damaging compaction has occurred, it is usually long-lasting (years or decades) and results in measurable growth losses on affected areas.

Given the potential seriousness of forest soil compaction, as well as the uncertainty surrounding its assessment, a project was initiated between the Nova Scotia Department of Natural Resources and the Nova Forest Alliance (NFA) model forest to document soil compaction levels associated with different harvesting operations and ground disturbance indicators.

Objectives of the ground disturbance / soil compaction project were:

1. To measure the impact of various forest harvesting operations on surface soil compaction.

2. To relate findings to specific soil types, machine traffic disturbance classes, and harvest system specifications.

3. To develop a soil compaction hazard guide for the model forest area.

Project details can be found in: *Quantifying Ground Disturbance and Soil Compaction - Final Report for the Nova Forest Alliance Model Forest* (Keys, 2005). This report describes field results as well as methods used to derive the compaction hazard matrix contained in this guide.

About This Guide

This guide contains information which can be used by contractors, planners, and woodlot owners to assess soil compaction hazards associated with forest harvesting operations within the NFA area.

Three main components make up this guide:

- A soil type map and soil type key for the NFA.
- A potential harvest impact class table.
- A compaction hazard matrix.

In addition, information is provided on:

- Harvest equipment ground pressures.
- Soil texture class assessment.
- Soil moisture class assessment.

Finally, examples are given of how the guide can be used to aid forest management planning.

NFA Soil Types

Forest soils within the NFA have been classified into 18 identifiable units based on soil texture, organic matter content, soil depth, and soil drainage class (see Table 1). Information on these soil types is found in *Forest Ecosystems of Nova Scotia's Model Forest* (Keys *et al*. 2003).

Since soil types can differ in their susceptibility to compaction, it is necessary to identify which soil type (or types) occur on any area slated for harvest. This is done in two ways:

- By using the NFA soil type map to identify likely soil types associated with the area of interest.
- By using the soil type key to verify soil type (or types) once on site.

Use of the soil type key (Figure 2) does not require extensive knowledge of forest soils. With information from the forest ecosystem classification guide (and a little experience), most soils can be classified in under five minutes.

Potential Harvest Impact (PHI) Class

To assess compaction hazard associated with different harvesting operations, it is necessary to categorize the relative potential impact of various harvesting systems. Different combinations of harvesting equipment, harvesting practices, and site features can result in different (or similar) levels of potential impact. Once this variable is classed, it can then be integrated with other variables to determine overall compaction hazard.

Ground pressure ratings associated with different harvesting equipment were used as the basis for developing PHI classes.

Table 1. NFA Soil Types.*

Soil Type	Name	Description
ST1	Dry - MCT	Dry, medium to coarse-textured soil
ST2	Fresh - MCT	Fresh, medium to coarse-textured soil
ST2-L	Fresh - MCT (Loamy)	Fresh, medium to coarse-textured soil, loamy surface
ST3	Moist - MCT	Moist, medium to coarse-textured soil
ST3-L	Moist - MCT (Loamy)	Moist, medium to coarse-textured soil, loamy surface
ST4	Wet - MCT	Wet, medium to coarse-textured soil
ST5	Fresh - FMT	Fresh, fine to medium-textured soil
ST6	Moist - FMT	Moist, fine to medium-textured soil
ST7	Wet - FMT	Wet, fine to medium-textured soil
ST8	Rich Fresh - MCT	Rich, fresh, medium to coarse-textured soil
ST9	Rich Moist - MCT	Rich, moist, medium to coarse-textured soil
ST10	Rich Wet - MCT	Rich, wet, medium to coarse-textured soil
ST11	Rich Fresh - FMT	Rich, fresh, fine to medium-textured soil
ST12	Rich Moist - FMT	Rich, moist, fine to medium-textured soil
ST13	Rich Wet - FMT	Rich, wet, fine to medium-textured soil
ST14	Very Wet - ORG	Very wet, dominantly organic soil
ST15	Dry Shallow - MCT	Dry, shallow, medium to coarse-textured soil
ST16	Moist Shallow - MCT	Moist, shallow, medium to coarse-textured soil

*** Soil Type 14 is an organic soil and is not included in this compaction hazard guide. Rutting (not compaction) is the main hazard associated with ST14 soils.**

Relative ratings were grouped as:

Low PHI - Maximum ground pressure less than 60 kPa
Medium PHI - Maximum ground pressure between 60-80 kPa
High PHI - Maximum ground pressure more than 80 kPa

These ranges were chosen based on analysis of field data and on an extensive review of harvesting equipment specifications provided by FERIC. The effect of adverse terrain conditions and use of slash mats were also integrated into PHI class determinantion (see Table 2).

Compaction Hazard Matrix

The compaction hazard matrix integrates all the variables that directly affect soil compaction and presents them in a way that allows for easy assessment of compaction hazard on a site-by site basis (see Figure 1). Hazard ratings used are:

Low: Impact is expected to include only minor areas (if any) with potentially growth-affecting soil compaction.

Moderate: Impact is expected to result in a high percentage of travelled area with potentially growth-affecting soil compaction.

High: Impact is expected to result in the majority of travelled area with potentially growth-affecting soil compaction.

The matrix presented in Figure 1 is a first approximation based on field data analyses and literature review. Although data were not collected for all matrix combinations, inferences made to fill information gaps follow a logic based on study results and soil type features:

- As soil moisture increases, so too does compaction hazard.
- As traffic level increases, so too does compaction hazard.
- As soil texture becomes finer, compaction hazard increases.
- Soils with similar textures have similar hazard ratings.
- Soils with organically enriched Ah/Ap horizons generally have lower hazard ratings than soils without these horizons (within the same texture range).

How To Use This Guide

This guide can be used for both pre-harvest planning and on-site operational planning. In general, users would follow these four steps:

1. Use Table 2 to determine PHI classes for all harvesting equipment being used.

2. Use the soil type map and soil type key (Figure 2) to determine expected and actual soil types found on planned harvest sites.

3. Use the compaction hazard matrix to determine likely impacts of your harvest system based on soil type, PHI class, likely and/or actual soil moisture class at time of treatment, and traffic class (Table 3).

4. Use this information to reduce the chances of soil compaction damage by:
    - appropriately matching equipment to site,
    - optimizing harvest scheduling to avoid working on wet sites,
    - designing trail layout and traffic patterns, and
    - planning for mitigation measures where necessary.

Points to Consider

1. Soil type names reflect their typical moisture condition. However, all soils can be found in a moist or wet condition depending on season and weather. Users are reminded that soil moisture class should be assessed before and during harvest operations (as needed) to more accurately estimate compaction hazard. Figure 3 shows how mositure can be quickly assessed in the field for fine to medium-textured soils.

2. All soil types have low compaction hazard when they are dry or frozen. However, soils which are typically moist or wet rarely reach a dry condition and soils do not always freeze sufficiently in winter to support harvesting equipment. Users should confirm soil conditions prior to beginning operations.

3. For forwarders and skidders, travel classes do not differentiate between empty and loaded trips - this is taken care of through the PHI class assigned to the machine(s) using the trail. If a particular trail is always used for empty traffic, the PHI class would be different than if the trail was used only for loaded trips or for two-way travel. Also, if harvesters travel on different trails than forwarders, expected impact on these trails would be based on the PHI class of the harvester alone.

4. PHI and travel classes are relative units. Users should exercise discretion when interpreting the compaction hazard ratings shown in Figure 1. For example, if the hazard rating for a particular combination of PHI class and travel class is listed as low to moderate; the user should err on the side of caution and call the impact moderate if machine ground pressure or the number of machine passes is at the high end of their respective classes.

5. Only compaction hazard is assessed in this guide. Users need to also consider other potential hazards such as rutting, erosion, and forest floor loss. Information on these hazard types can be found in *Forest Ecosystems of Nova Scotia's Model Forest* (Keys *et al*. 2003).

Sample Applications

Use of this guide is best illustrated using specific examples. These will show how the guide can be used for both harvest planning and day-to-day decision making. In all examples discussed, it is assumed that minimizing soil compaction is a management goal.

Example 1.

Four sites have been identified for harvest starting as soon as possible in the spring. Based on the soil type map, you determine that these sites are likely underlain by the following soils:

Site A:	ST2	Fresh, medium to coarse-textured soil
Site B:	ST3	Moist, medium to coarse-textured soil
Site C:	ST2-L	Fresh, medium to coarse-textured soil, loamy surface
Site D:	ST6	Moist, fine to medium-textured soil

Question: How does this information influence harvest scheduling?

Answer: Subject to field verification of soil type, the best order of harvest would be: Site A, Site C, Site B, then Site D.

Explanation:

- ST2 and ST3 soils are the coarsest and least prone to compaction, followed by ST2-L and ST6 soils (Figure 1). However, ST3 soils are typically moist (meaning they are imperfectly drained) and would not be accessible as early in the season as ST2 and ST2-L sites (Table 1).

- Both ST2 and ST2-L soils are fresh soil types, meaning they are generally well to moderately well drained. However, ST2 soils are coarser and would drain more quickly after snow melt and spring rains. This makes Site A the best candidate for initial harvest over Site C.

- Since both ST3 and ST6 soils are typically moist (imperfectly drained), Sites B and D would be too wet to harvest in the spring. However, ST3 soils are coarser than ST6 soils, suggesting Site B would dry more quickly as summer progressed. This would likely put Site B ahead of Site D in the harvest schedule. If weather was such that Site D did dry to a fresh condition during the time Site B was being harvested, then priority would shift to Site D to take advantage of these short-term conditions.

- Depending on weather patterns, it may be that Site D never gets to a fresh condition during the summer harvest season. In this case, other measures would need to be taken to reduce compaction on this site (see Example 2), or the harvest postponed until winter if it was expected the ground would be frozen at that time.

Example 2.

You are about to harvest an area which will take 4-6 weeks to complete. Based on your pre-harvest assessment, you have confirmed that the area is mainly underlain by ST6 soils.

Question: How does this information impact your harvest plan?

Answer: ST6 soils are fine to medium-textured and typically moist. Based on Figure 1, this site would be very susceptible to compaction under normal conditions. Even if the site was currently in a fresh condition, one rain event is all that is needed to put the site back into a long-term moist condition. Given the expectation of dealing with a moist ST6 soil, there are several things that can be done to reduce soil compaction at this site:

- Use a low PHI class harvest system.
- Plan and use a trail system that minimizes the area travelled by machines.
- Try to establish main haul trails on higher ground.
- Build and maintain trails so that rutting does not require new trails to be established.

Moist/wet ST6 soils are susceptible to compaction even under light to moderate traffic levels. A well planned and maintained trail system concentrates machine travel on less area, thereby reducing the overall extent of soil compaction on the site.

Example 3.

You have two harvest operations on the go about a kilometer away from each other. Harvesters at both sites are low PHI machines, while forwarders are both medium PHI machines. It rained most of the night, you need to decide the next morning whether to send your crews out or to have them address some equipment maintenance issues. Site A is underlain by an ST2 soil and Site B by an ST5 soil.

Question: How does soil type information influence your decision?

Answer: ST2 and ST5 soils are both fresh soil types meaning they are well to moderately well drained (Table 1). However, after a night of steady rain, both soils would likely be in a moist to wet condition. Because ST5 soils are fine to medium-textured, they have a greater compaction hazard than ST2 soils when moist, and they drain slower than ST2 soils. Given this information, it is clear that Site B would have a moderate to high compaction hazard for at least a couple of days (Figure 1), whereas Site A would have a low to moderate hazard. Based on this knowledge, there are two viable options:

1. Have crews at both sites attend to maintenance issues. When servicing is completed, have both sets of equipment work Site A until Site B returns to a fresh condition. At this point, both crews could be sent back to Site B to catch up.

2. Since the harvesters are low PHI machines, have both harvesters work Site A while forwarders are being serviced. This option allows harvesting to continue, but gives Site A more time to drain before forwarding operations resume, thereby reducing the likelihood of damaging compaction from moderate to heavy forwarder traffic. When servicing is complete, forwarders can rejoin operations while the harvesters are serviced. As in option 1, both sets of equipment would then continue to work Site A until Site B returns to a fresh condition.

Acknowledgements

Thanks to Ismo Makkonen (Forest Engineering Research Institute of Canada) for providing examples of machine data and calculated ground pressures for use in this guide.

Table 2. Look-up table to determine potential harvest impact (PHI) class of harvesting equipment.

Maximum Equipment Ground Pressure Rating (kPa)	Maximum Equipment Ground Pressure Rating (psi)	Base PHI Class	Adjusted PHI Class	
			Softwood Slash Mat	Steep Slope and/or Uneven Terrain
40 or less	5.8 or less	**Low**	Low	Low
45	6.5	**Low**	Low	Low
50	7.3	**Low**	Low	Medium
55	8.0	**Low**	Low	Medium
60	8.7	**Medium**	Low	Medium
65	9.4	**Medium**	Low	High
70	10.2	**Medium**	Low	High
75	10.9	**Medium**	Low	High
80	11.6	**High**	Medium	High
85	12.3	**High**	Medium	High
90	13.1	**High**	Medium	High
95	13.8	**High**	Medium	High
100	14.5	**High**	Medium	High
105	15.2	**High**	High	High
110 or more	16.0 or more	**High**	High	High

1. Determine the maximum ground pressure rating for your equiipment based on manufacturer specifications (eg. if listed as 63 kPa by the manufacturer, Table rating = 60). If manufacturer data are not available, match your equipment with examples in Appendix 1 to estimate ground pressure.

2. Use the base PHI class associated with your maximum ground pressure rating for use in the compaction hazard matrix (Figure 1) - unless adjustments apply.

3. For slash mat adjustments to apply, slash mats must be well constructed (no visible ground) and remain intact throughout the harvest operation. Use the steep slope adjustment for slopes of 20% or greater. Use the uneven terrain adjustment where sites are strongly mounded (mounds at least 0.5 m in height, and less than 5 m apart) or where surface stones are common (less than 5 m apart). Where both the slash mat and slope/terrain adjustments apply, the base PHI class should be used.

Table 3. Traffic classes used in the compaction hazard matrix (Figure 1).

Light (TC-L)	Moderate (TC-M)	Heavy (TC-H)
1-2 Passes*	3-7 Passes	8+ Passes

* Pass counts can include traffic by any piece of harvest equipment - differences in expected impact are captured by the PHI class assigned to the machine(s) used.

Figure 1. Compaction hazard matrix for NFA soil types as influenced by soil moisture class, potential harvest impact class (PHI), and traffic class (TC). Note: All soils have a low compaction hazard (regardless of PHI class and traffic class) when they are dry or frozen.

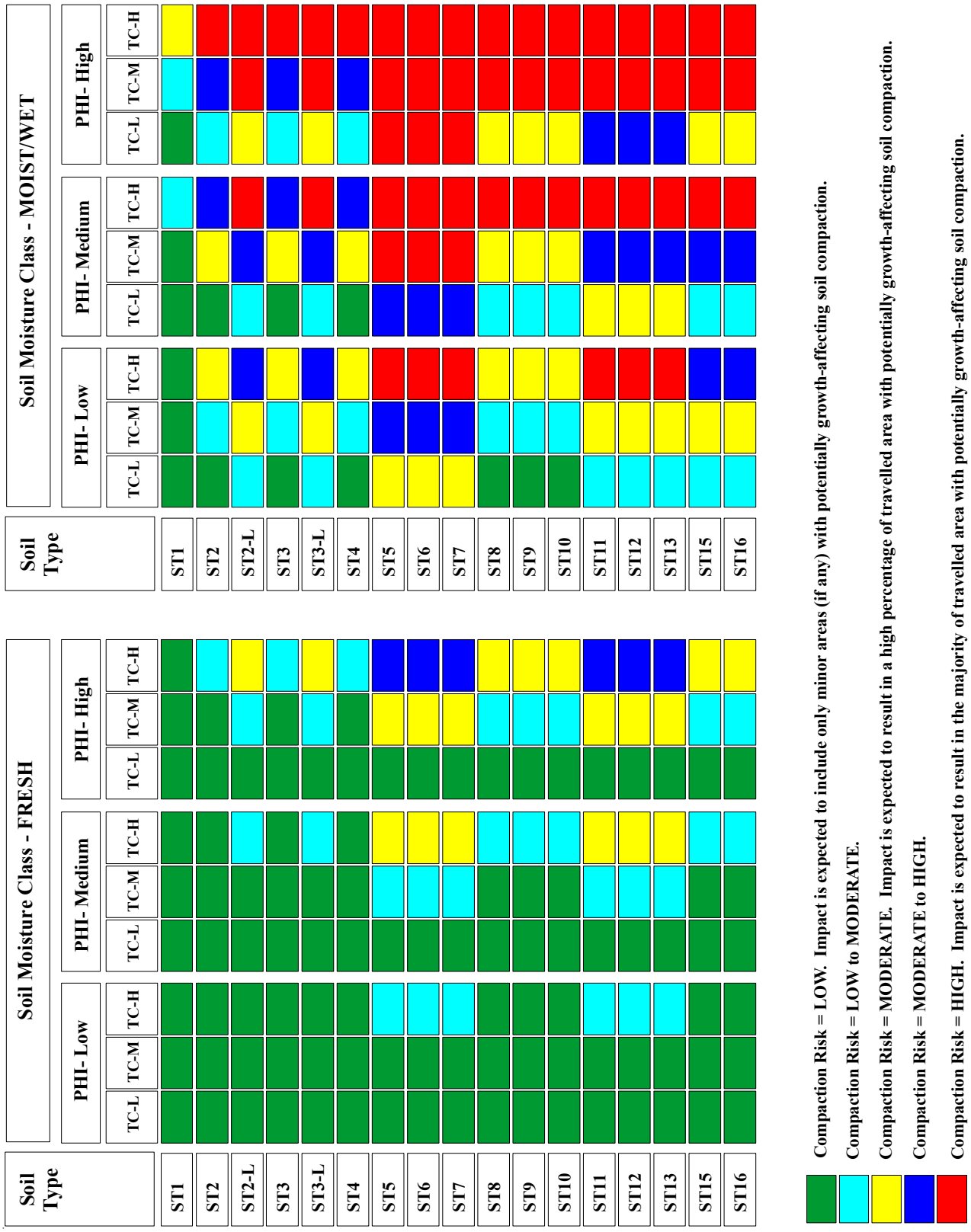
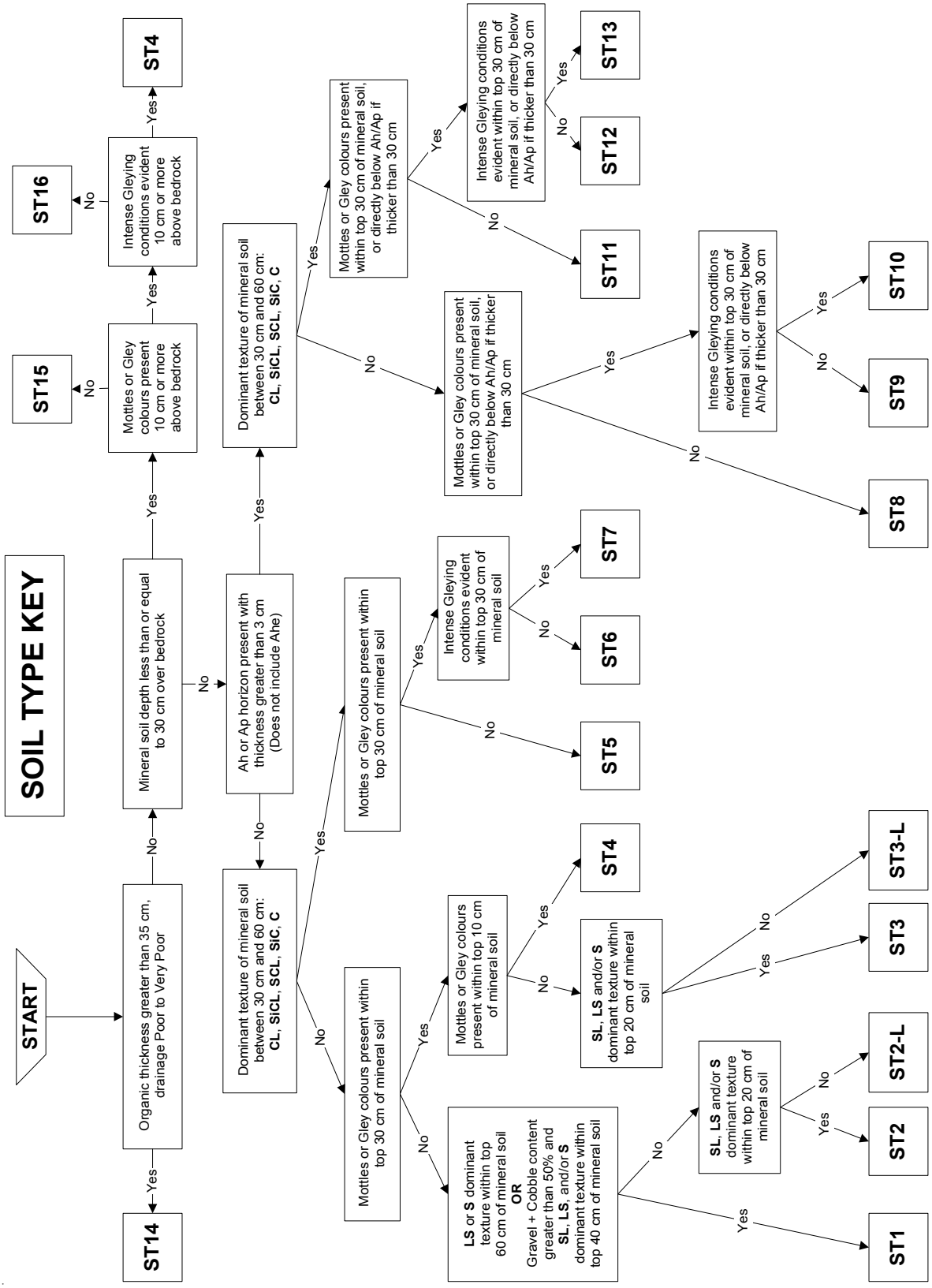


Figure 2. NFA Soil Type Key and Soil Texture Key - from *Forest Ecosystems of Nova Scotia's Model Forest* (Keys *et al.* 2003). CL = Clay loam, SiCL = Silty clay loam, SCL = Sandy clay loam, SiC = Silty clay, C = Clay, SL = Sandy loam, LS = Loamy sand, S = Sand.



Soil Texture Key:

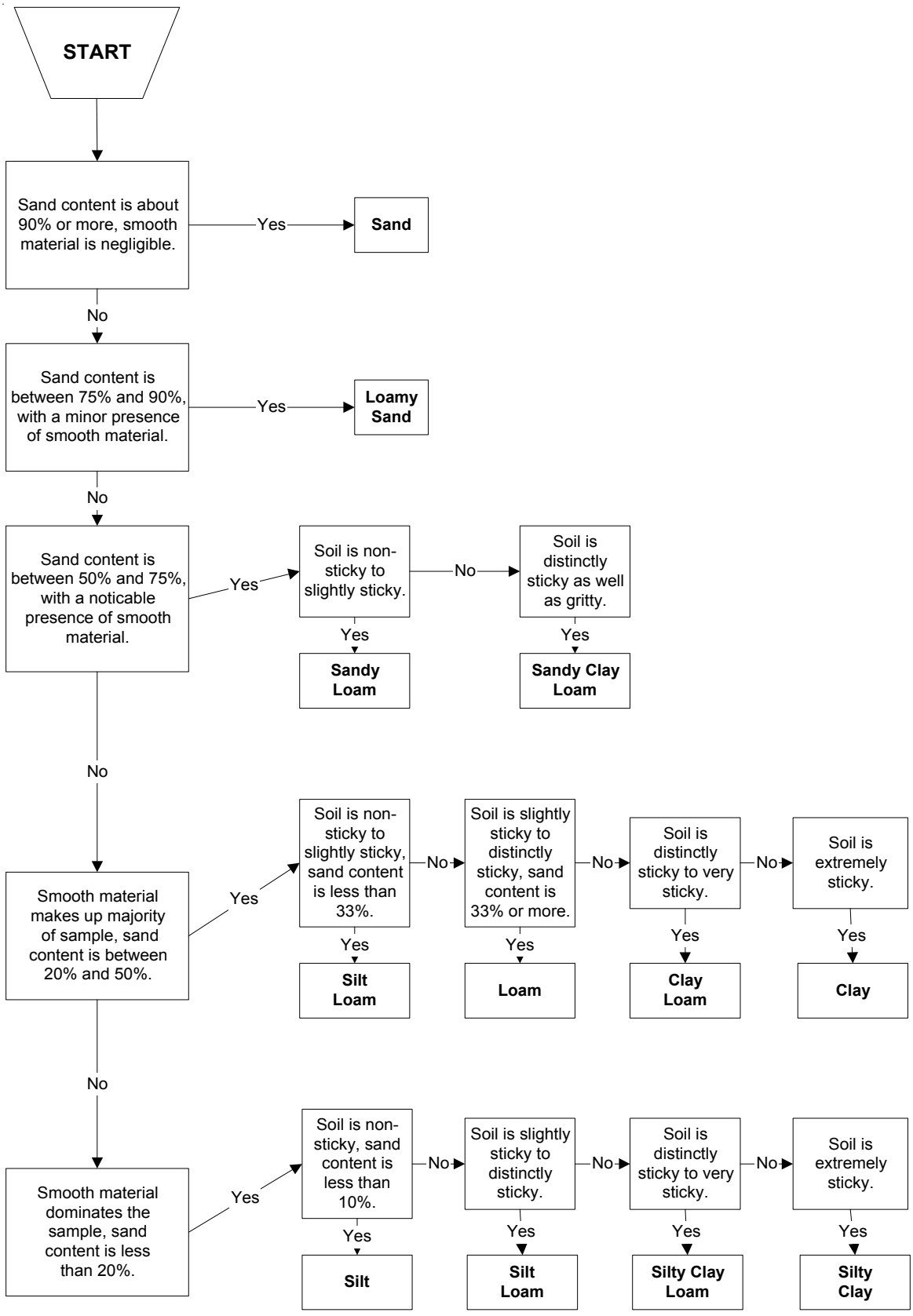


Figure 3. Soil Moisture Class Assessment for Fine to Medium-Textured Soils.*

Obtain a soil sample from the wettest area within the top 30 cm of soil and mold the soil into a clod:

If when squeezed or flattened the soil clod does not crumble, it is in a wet condition.

If the soil is easy to mold, but breaks when squeezed, it is in a moist condition.

If the soil cannot be molded by hand, but is still friable, it is in a fresh condition.

* Adapted from: Sutherland, B. 2003. FERIC Advantage Publication Volume 4 No. 7.
Photos courtesy of Andrei Startsev, Alberta Research Council.

Appendix 1. Examples of Ground Pressures Related to Different Harvesting Equipment.

Note: These are calculated examples, manufacturer data should be used first whenever possible. Users should match as closely as possible equipment specifications with those listed below. The maximum ground pressure value associated with the equipment configuration should then be used to determine equipment PHI class in Table 2.

Examples for 4-Wheel Forwarders

Load Rating (kg)	Tires Front	Tires Back	Notes	Width (m)	Axel Weight Front Empty (kg)	Axel Weight Rear Empty (kg)	Axel Weight Front Loaded (kg)	Axel Weight Rear Loaded (kg)	Ground Pressure Front Empty (kPa)	Ground Pressure Rear Empty (kPa)	Ground Pressure Front Loaded (kPa)	Ground Pressure Rear Loaded (kPa)
7260	24.5-32	24.5-32		3.02	6675	4590	6902	11623	58	40	59	100
	30.5L-32	30.5L-32		3.16	6901	4816	7128	11849	47	33	49	81
	67x34.0-26	67x34.0-26		3.07	6875	4790	7102	11823	45	31	46	77
	66x43.0-26	66x43.0-26		3.48	6925	4840	7152	11873	37	26	39	64
	68x50.0-32	68x50.0-32		--	7827	5742	8054	12775	35	25	36	56
10000	28L-26	28L-26		2.86	6120	4880	6224	14776	51	41	52	124
	66x43.0-26	66x43.0-26		3.54	6436	5196	6540	15092	35	28	35	82

Examples for 6-Wheel Forwarders

Load Rating (kg)	Tires Front	Tires Back	Notes	Width (m)	Axel Weight Front Empty (kg)	Axel Weight Rear Empty (kg)	Axel Weight Front Loaded (kg)	Axel Weight Rear Loaded (kg)	Ground Pressure Front Empty (kPa)	Ground Pressure Rear Empty (kPa)	Ground Pressure Front Loaded (kPa)	Ground Pressure Rear Loaded (kPa)
6780	19.5L x 24	400/55-22.5		--	5382	1782	6237	7707	77	21	89	93
	21L x 24	500/45-22.5			5417	1862	6272	7787	73	18	85	75
10000	600/65-34	600/55-26.5		2.54	5170	4790	5170	14790	51	29	52	91
	600/65-34	600/55-26.5	Tracks		5170	6110	5170	16110	51	17	52	44
12000	600/65-34	600/55-26.5		2.64	6910	5490	5170	17430	69	34	51	107
	600/65-34	600/55-26.5	Tracks		6910	6810	5170	18810	69	19	51	51
	700/55-34	700/50-26.5		2.75	7010	5680	5270	17620	60	30	45	93
	700/55-34	700/50-26.5	Tracks		7010	7280	5270	19220	60	18	45	46
14000	600/65-34	600/55-26.5		2.75	8250	6340	8250	20340	82	39	82	125
	600/65-34	600/55-26.5	Tracks		8250	7660	8250	21660	82	21	82	59
	700/55-34	700/50-26.5		2.93	8350	6540	8350	20540	72	34	72	108
	700/55-34	700/50-26.5	Tracks		8350	8160	8350	22160	72	20	72	54
17000	23.1-34	650/65-26.5		2.99	10000	8300	10309	24991	92	42	95	127
	23.1-34	650/65-26.5	Tracks		10000	10050	10309	26741	92	23	95	62
	700/70-34	750/55-26.5		2.99	10140	8470	10449	25161	77	37	79	111
	700/70-34	750/55-26.5	Tracks		10140	10420	10449	27111	77	22	79	56

Examples for 8-Wheel Forwarders

Load Rating (kg)	Tires Front	Tires Back	Notes	Width (m)	Axel Weight Front Empty (kg)	Axel Weight Rear Empty (kg)	Axel Weight Front Loaded (kg)	Axel Weight Rear Loaded (kg)	Ground Pressure Front Empty (kPa)	Ground Pressure Rear Empty (kPa)	Ground Pressure Front Loaded (kPa)	Ground Pressure Rear Loaded (kPa)
9500	500/60-22.5	500/60-22.5		2.35	6500	4500	6500	14000	55	38	55	117
	500/60-22.5	500/60-22.5	Tracks		7460	5460	7460	14960	27	20	27	54
	600/50-22.5	600/50-22.5		2.55	6580	4580	6580	14580	46	32	46	102
	600/50-22.5	600/50-22.5	Tracks		7700	5700	7700	15700	24	18	24	49
	700/45-22.5	700/45-22.5		2.73	6675	4675	6675	14675	40	28	40	88
	700/45-22.5	700/45-22.5	Tracks		7955	5955	7955	15955	23	17	23	47
10000	600/50-22.5	600/50-22.5		2.46	7000	5000	7000	15000	49	35	49	105
	600/50-22.5	600/50-22.5	Tracks		8120	6120	8120	16120	26	19	26	51
	700/45-22.5	700/45-22.5		2.66	7090	5090	7090	15090	42	31	42	90
	700/45-22.5	700/45-22.5	Tracks		8370	6370	8370	16370	24	19	24	48
11000	600/55-26.5	600/55-26.5		2.5	8500	5500	8500	16500	52	34	52	101
	600/55-26.5	600/55-26.5	Tracks		9820	6820	9820	17820	27	19	27	49
	700/50-26.5	700/50-26.5		2.7	8690	5690	8690	16690	46	30	46	88
	700/50-26.5	700/50-26.5	Tracks		10290	7290	10290	18290	25	18	25	45

Examples for 8-Wheel Forwarders Continued...

Load Rating (kg)	Tires Front	Tires Back	Notes	Width (m)	Axel Weight Front Empty (kg)	Axel Weight Rear Empty (kg)	Axel Weight Front Loaded (kg)	Axel Weight Rear Loaded (kg)	Ground Pressure Front Empty (kPa)	Ground Pressure Rear Empty (kPa)	Ground Pressure Front Loaded (kPa)	Ground Pressure Rear Loaded (kPa)
11000	600/55-26.5	600/55-26.5		2.5	9000	5500	9000	16500	55	34	55	101
	600/55-26.5	600/55-26.5	Tracks		10320	6820	10320	17820	29	19	29	49
	700/50-26.5	700/50-26.5		2.7	9190	5690	9190	16690	48	30	48	88
	700/50-26.5	700/50-26.5	Tracks		10790	7290	10790	18290	26	18	26	45
12000	600/55-26.5	600/55-26.5		2.72	9000	6000	9000	18000	55	37	55	110
	600/55-26.5	600/55-26.5	Tracks		10320	7320	10320	19320	29	20	29	53
	700/50-26.5	700/50-26.5		2.87	9190	6190	9190	18190	48	33	48	96
	700/50-26.5	700/50-26.5	Tracks		10790	7790	10790	19790	26	19	26	48
14000	700/50-26.5	700/50-26.5		2.94	9500	6500	9500	20500	50	34	50	108
	700/50-26.5	700/50-26.5	Tracks		11100	8100	11100	22100	27	20	27	53
	800/45-26.5	800/45-26.5		3.08	9710	6710	9710	20710	45	31	45	95
	800/45-26.5	800/45-26.5	Tracks		11400	8400	11400	22400	25	18	25	49

Examples for Farm Tractor and ATV Trailers

Equipment	Axel Weight Front (kg)	Axel Weight Rear (kg)	Axel Weight Trailer (kg)	Total Weight (kg)	Ground Pressure Front (kPa)	Ground Pressure Rear (kPa)	Ground Pressure Trailer (kPa)	Maximum Ground Pressure (kPa)
110 hp tractor and 8 tonne trailer: Load 0 kg	1898	3752	1850	7500	39	50	26	50
110 hp tractor and 8 tonne trailer: Load 8000 kg	1608	5895	7996	15500	33	79	111	111
110 hp tractor and 8 tonne trailer: Load 4000 kg	1753	4823	4923	11500	36	64	68	68
ATV and trailer: Load 0 kg	161	389	400	950	12	24	13	24
ATV and trailer: Load 1360 kg	136	532	1643	2310	10	33	52	52
ATV and trailer: Load 680 kg	148	461	1021	1630	11	28	32	32

Examples for 4-Wheel Cable Skidders

Weight Class	Tires Front	Tires Back	Width (m)	Axel Weight Front Empty (kg)	Axel Weight Rear Empty (kg)	Axel Weight Front Loaded (kg)	Axel Weight Rear Loaded (kg)	Ground Pressure Front Empty (kPa)	Ground Pressure Rear Empty (kPa)	Ground Pressure Front Loaded (kPa)	Ground Pressure Rear Loaded (kPa)
7 tonne	18.4-34	18.4-34	2.71	4355	3030	3296	5085	54	38	41	64
	23.1-26	23.1-26	2.71	4375	3050	3325	5097	45	31	34	52
	28L-26	28L-26	2.97	4485	3160	3432	5210	38	26	29	44
	24.5-32	24.5-32	2.79	4635	3310	3541	5401	40	29	30	47
10 tonne	23.1-26	23.1-26	2.77	6895	3629	5567	6378	71	37	57	65
	28L-26	28L-26	2.98	7005	3739	5674	6491	59	31	48	54
	24.5-32	24.5-32	2.97	7155	3889	5779	6686	62	33	50	58
	30.5L-32	30.5L-32	3.12	7315	4049	5927	6858	50	28	40	47
	67x34.0-26	67x34.0-26	--	7325	4059	5973	6832	48	27	39	45
11 tonne	23.1-26	23.1-26	2.96	6900	4396	5593	7228	71	45	57	74
	28L-26	28L-26	3.08	7010	4506	5701	7340	59	38	48	61
	24.5-32	24.5-32	2.97	7160	4656	5806	7535	62	40	50	65
	30.5L-32	30.5L-32	3.28	7320	4816	5954	7707	50	33	41	53
	35.5L-32	35.5L-32	--	7540	5036	6134	7967	39	26	32	41
15 tonne	30.5L-32	30.5L-32	3.29	9571	5580	7583	9614	65	38	52	66
	35.5L-32	35.5L-32	3.70	9791	5800	7756	9856	51	30	40	51
	67x34.0-26	67x34.0-26	--	9581	5590	7593	9594	62	36	49	63
	68x50.0-32	68x50.0-32	--	9871	5880	7883	9914	43	26	35	44
	78x44.0-32	78x44.0-32	--	9991	6000	7956	10085	46	28	37	47

Examples for 4-Wheel Grapple Skidders

Weight Class	Tires Front	Tires Back	Width (m)	Axel Weight Front Empty (kg)	Axel Weight Rear Empty (kg)	Axel Weight Front Loaded (kg)	Axel Weight Rear Loaded (kg)	Ground Pressure Front Empty (kPa)	Ground Pressure Rear Empty (kPa)	Ground Pressure Front Loaded (kPa)	Ground Pressure Rear Loaded (kPa)
7 tonne	18.4-34	18.4-34	2.71	4287	4514	2599	7390	54	56	33	92
	23.1-26	23.1-26	2.71	4307	4534	2619	7410	44	46	27	76
	28L-26	28L-26	2.97	4417	4644	2729	7520	37	39	23	63
	24.5-32	24.5-32	2.79	4567	4794	2879	7670	39	41	25	66
8 tonne	23.1-26	23.1-26	2.77	7031	4550	4911	8234	72	47	50	84
	28L-26	28L-26	2.98	7141	4660	5021	8344	60	39	42	70
	24.5-32	24.5-32	2.97	7291	4810	5171	8494	63	41	45	73
	30.5L-32	30.5L-32	3.12	7451	4970	5331	8654	51	34	36	59
	67x34.0-26	67x34.0-26	--	7461	4980	5341	8664	49	32	35	56
9 tonne	23.1-26	23.1-26	2.77	6142	5852	3946	9667	63	60	40	99
	28L-26	28L-26	2.98	6252	5962	4056	9777	52	50	34	82
	24.5-32	24.5-32	2.97	6402	6112	4206	9927	55	53	36	85
	30.5L-32	30.5L-32	3.12	6562	6272	4366	10087	45	43	30	69
	67x34.0-26	67x34.0-26	--	6572	6282	4376	10097	43	41	29	66
10 tonne	23.1-26	23.1-26	2.96	7008	5693	4572	9915	72	58	47	101
	28L-26	28L-26	3.08	7118	5803	4682	10025	60	49	39	84
	24.5-32	24.5-32	2.97	7268	5953	4832	10175	63	51	42	88
	30.5L-32	30.5L-32	3.28	7428	6113	4992	10335	51	42	34	70
	35.5L-32	35.5L-32	--	7648	6333	5212	10555	40	33	27	55
14 tonne	30.5L-32	30.5L-32	3.29	8964	8646	5788	14200	61	59	39	97
	35.5L-32	35.5L-32	3.70	9184	8866	6008	14420	48	46	31	75
	67x34.0-26	67x34.0-26	--	8974	8656	5798	14210	58	56	38	93
	68x50.0-32	68x50.0-32	--	9264	8946	6088	14500	41	39	27	64
	78x44.0-32	78x44.0-32	--	9384	9066	6208	14620	44	42	29	68

Examples for 6-Wheel Harvesters

Size	Tires Engine End	Tires Loader End	Notes	Width (m)	Engine End Axle Weight (kg)	Loader End Axle Weight (kg)	Total Weight (kg)	Ground Pressure Engine End (kPa)	Ground Pressure Loader End (kPa)
Small	650/65-26.5	600/50-22.5		2.62	5040	9000	14040	51	63
	650/65-26.5	600/50-22.5	Tracks		5040	10120	15160	51	31
	600/60-30.5	700/45-22.5		2.78	5040	9090	14130	55	54
	600/60-30.5	700/45-22.5	Tracks		5040	10370	15410	55	28
Medium	600/65-34	600/55-26.5		2.78	5950	9050	15000	59	56
	600/65-34	600/55-26.5	Tracks		5950	10350	16300	59	29
	700/55-34	700/50-26.5		2.88	6050	9240	15290	52	49
	700/55-34	700/50-26.5	Tracks		6050	10820	16870	52	27
Medium	600/65-34	600/55-26.5		2.68	6150	10750	16900	61	66
	600/65-34	600/55-26.5	Tracks		6150	12070	18220	61	33
	700/55-34	700/50-26.5		2.86	6250	10940	17190	54	58
	700/55-34	700/50-26.5	Tracks		6250	12520	18770	54	30
Medium	600/65-34	600/55-26.5		2.74	6500	11000	17500	65	68
	600/65-34	600/55-26.5	Tracks		6500	12320	18820	65	34
	700/55-34	700/50-26.5		2.93	6600	11190	17790	57	59
	700/55-34	700/50-26.5	Tracks		6600	12770	19370	57	31
Large	700/55-34	700/50-26.5		2.99	6800	11150	17950	58	59
	700/55-34	700/50-26.5	Tracks		6800	12730	19530	58	31
	66x43.0-26	800/45-26.5		3.67	7150	11340	18490	40	52
	66x43.0-26	800/45-26.5	Tracks		7150	13030	20180	40	28
Large	700/70-34	650/65-26.5		3.00	7050	11950	19000	54	61
	700/70-34	650/65-26.5	Tracks		7050	13700	20750	54	32
	700/70-34	750/55-26.5		3.04	7050	12120	19170	54	62
	700/70-34	750/55-26.5	Tracks		7050	14070	21120	54	29

Examples for 4-Wheel Harvesters

Tires Engine End	Tires Loader End	Width (m)	Engine End Axle Weight (kg)	Loader End Axle Weight (kg)	Total Weight (kg)	Ground Pressure Engine End (kPa)	Ground Pressure Loader End (kPa)
500/60-26.5	500/60-26.5	1.80	2310	3240	5550	34	48
23.1-26	23.1-26	2.5/2.8	5100	5900	11000	52	60
28L-26	28L-26	2.75	5210	6010	11220	44	50
23.1-26	23.1-26	2.5/2.8	6100	7500	13600	62	77
28L-26	28L-26	2.75	6210	7610	13820	52	64
650/65-34	650/65-34	2.75	7200	8000	15200	72	80
700/55-34	700/55-34	2.90	7300	8010	15310	63	69

Examples for Farm Tractor Based Harvesters

Tires Engine End	Tires Loader End	Width (m)	Engine End Axle Weight (kg)	Loader End Axle Weight (kg)	Total Weight (kg)	Ground Pressure Engine End (kPa)	Ground Pressure Loader End (kPa)
18.4-34	16.9-30	2.0/2.2	2900	3300	6200	36	51
18.4-38	16.9-34	2.0/2.2	2950	3350	6300	35	48
18.4-38	16.9-34	--	3800	4400	8200	45	63
20.8-38	23.1-26	--	3920	4470	8390	40	46
16.9-28	20.8-38	2.25	3675	7300	10975	59	74
650/65-26.5	700/70-34	2.60	3775	7380	11155	38	56
18.4-26	18.4-26	--	3050	4000	7050	44	58
650/65-26.5	650/65-26.5	--	3290	4240	7530	33	43
13.6-28	16.9-38	2.14	2180	5225	7405	45	70
14.9-28	18.4-38	2.14	2205	5292	7497	41	60
16.9-28	20.8-38	2.24	2290	5355	7645	35	51
480/65-28	600/65-38	--	2300	5360	7660	35	51

Examples for Tracked Harvesters

Width (m)	Pad Width (m)	Track Contact Length (m)	Track Wheel Radius (m)	Total Weight (kg)	Ground Pressure (kPa)
2.40	0.500	2.74	0.350	12125	37
2.90	0.600	3.18	0.400	15650	35
2.59	0.610	2.80	0.400	17800	43
3.05	0.610	3.35	0.457	23200	48
--	0.711	3.35	0.457	23650	42
--	0.813	3.35	0.457	24100	37
3.15	0.610	3.62	0.425	29100	56
--	0.711	3.62	0.425	29600	49
--	0.914	3.62	0.425	30600	40
3.63	0.610	3.94	0.457	35200	63
--	0.711	3.94	0.457	35750	55
--	0.813	3.94	0.457	36300	49
--	0.914	3.94	0.457	36300	43

Examples for Feller-Bunchers

Width (m)	Pad Width (m)	Track Contact Length (m)	Track Wheel Radius (m)	Total Weight (kg)	Ground Pressure (kPa)
3.05	0.610	3.99	0.457	26550	47
3.15	0.710	3.99	0.457	27040	41
3.20	0.760	3.99	0.457	27310	39
3.36	0.915	3.99	0.457	28010	33
3.15	0.610	3.61	0.457	27000	52
3.25	0.710	3.61	0.457	27450	45
3.30	0.760	3.61	0.457	27690	43
3.46	0.915	3.61	0.457	28320	36
3.33	0.610	3.99	0.457	36160	64
3.43	0.710	3.99	0.457	36650	56
3.48	0.760	3.99	0.457	36920	52
3.64	0.915	3.99	0.457	37620	44