ASAE D497.5 FEB2006
Agricultural Machinery Management Data

American Society of
Agricultural and Biological Engineers

STANDARD

ASABE, 2950 Niles Road, St. Joseph, MI 49085-9659, USA ph. 269-429-0300, fax 269-429-3852, hq@asabe.org

Agricultural Machinery Management Data

Developed by the Farm Machinery Management Committee; approved by the Power and Machinery Division Standards Committee; adopted by ASAE February 1963 as ASAE D230; revised December 1965, February 1971; revised editorially December 1974; revised December 1977; revised editorially September 1979; Table 1 corrected December 1981; reconfirmed December 1982; revised December 1983; reconfirmed December 1988; revised March 1990 and redesignated ASAE D497; revised editorially December 1990; revised March 1993, March 1994; revised editorially January 1995; revised November 1996, January 1998; revised editorially March 1999, February 2000; reaffirmed February 2003; revised February 2006.

1 Purpose and scope

1.1 These data include representative values of farm machinery operation parameters as an aid to managers, planners, and designers in estimating the performance of field machines.

1.2 These data are intended for use with ASAE EP496. Some data are reported in equation form to permit use in computer and calculator mathematical models.

1.3 These data report typical values for tractor performance, implement power requirements, repair and maintenance costs, depreciation, fuel and oil use, reliability for field operation, probable working days, and timeliness coefficients as measured by experiment, modeling, or survey.

1.4 Where possible, variation in sampled data is reported using the range, a standard deviation, SD, or a coefficient of variation, CV, defined as SD/mean. In a normal distribution 68% of the population should be contained in a range of ± 1 SD about the mean, and 95% will be contained in a ± 2 SD.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Data. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Data are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Standards organizations maintain registers of currently valid standards.

2.1 ASAE S296.5 DEC03, *General Terminology for Traction of Agricultural Traction and Transport Devices and Vehicles*

2.2 ASAE S313.3 FEB04, *Soil Cone Penetrometer*

2.3 ASAE S495.1 NOV2005, *Uniform Terminology for Agricultural Machinery Management*

2.4 ASAE EP496.3 FEB2006, *Agricultural Machinery Management*

3 Tractor performance

3.1 Drawbar performance of tractors depends primarily on engine power, weight distribution on drive wheels, type of hitch, and soil surface. Maximum tractive efficiency, *TE*, is optimized by compromising drive wheel slip, *s*, and motion resistance, *MR*. Figure 1 presents typical power relationships for agricultural tractors when properly ballasted for the desired operating speed. Tractive efficiency can be approximated by the ratio between PTO power and drawbar power. Four surface conditions and four types of tractors are included variables. The drive tire size is that just large enough to carry the expected dynamic loading.

3.2 Single-wheel performance equations for pneumatic tires are useful for design specifications, prediction of vehicle performance, and computer simulation of vehicle productivity. The following relationships apply to bias-ply tires on most agricultural, earthmoving, and forestry prime movers. The following equations are limited to tires with a b/d ratio ranging from 0.1 to 0.7, static radial tire deflections ranging from 10% to 30% of the undeflected tire section height, and W/bd values ranging from 15 to 55 kN/m^2.

3.2.1 Motion resistance, *MR*, (as defined in ASAE S296) is equal to the difference between gross traction, *GT*, and net traction, *NT*:

$$MR = GT - NT = W\left(\frac{1}{B_n} + 0.04 + \frac{0.5s}{\sqrt{B_n}}\right)$$

where:

$$B_n = \left(\frac{CIb\ d}{W}\right)\left(\frac{1+5\frac{\delta}{h}}{1+3\ \frac{b}{d}}\right)$$

- B_n is a dimensionless ratio;
- W is the dynamic wheel load in force units normal to the soil surface, kN (lbf);
- CI is the cone index for the soil (see ASAE S313), kPa (lbf/in.^{2});
- b is the unloaded tire section width, m (in.);
- d is the unloaded overall tire diameter, m (in.);
- h is the tire section height, m (in.);
- δ is the tire deflection, m (in.);
- s is slip (see ASAE S296), decimal.

3.2.1.1 Values of CI and B_n for agricultural drive tires ($W/bd \cong 30$ kN/m^2) on typical soil surfaces are:

Soil	*CI* (kPa)	B_n
Hard	1800	80
Firm	1200	55
Tilled	900	40
Soft, sandy	450	20

These values are applicable to soils that are not highly compactible.

3.2.1.2 The motion resistance ratio, ρ, is a ratio of the motion resistance to dynamic wheel load.

$$\rho = \frac{MR}{W} = \frac{1}{B_n} + 0.04 + \frac{0.5\ s}{\sqrt{B_n}}$$

3.2.2 Net traction, *NT* (as defined in ASAE S296):

$$NT = W\left(0.88(1-e^{-0.1B_n})(1-e^{-7.5\ s}) - \frac{1}{B_n} - \frac{0.5\ s}{\sqrt{B_n}}\right)$$

where:

e is the base of natural logarithms.

3.2.3 Gross traction, *GT* (as defined in ASAE S296):

$$GT = W(0.88(1-e^{-0.1\ B_n})(1-e^{-7.5\ s}) + 0.04)$$

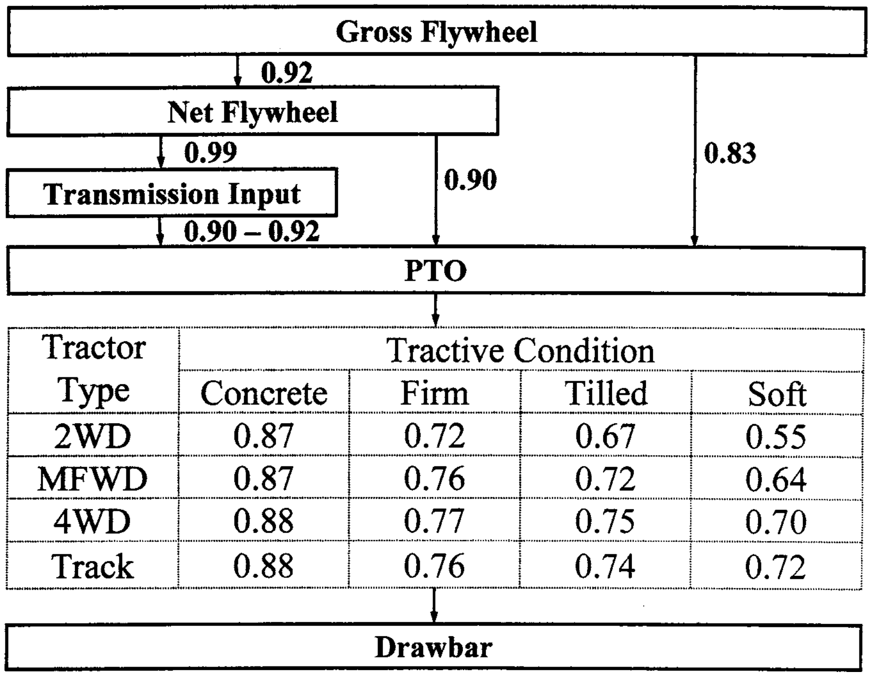

Figure 1 – Power relationships for agricultural tractors. Power at a given location in the drive train can be used to estimate power at another location. For example, PTO power can be estimated from net flywheel power by multiplying the net flywheel power by 0.90. If drawbar power is desired, choose the tractor type and tractive condition to determine the ratio. To estimate the drawbar power for a four-wheel drive tractor with 224 kW of net flywheel power operating on firm soil, multiply 224 by 0.90 and 0.77 to arrive at 155.23 kW.

3.2.4 Tractive efficiency, *TE*:

$$TE=(1-s)\,\frac{NT}{GT}$$

3.3 Fuel efficiency varies by type of fuel and by percent load on the engine. Typical farm tractor and combine engines above 20% load are modeled by the equations below. Typical fuel consumption for a specific operation is given in L/kW·h (gal/hp·h) where X is the ratio of equivalent PTO power required by an operation to that maximum available from the PTO. These equations model fuel consumptions 15% higher than typical Nebraska Tractor Test performance to reflect loss of efficiency under field conditions. To determine the average fuel consumption of a tractor operating under a range of load conditions, over a period of time, refer to ASAE EP496.

Gasoline	$2.74X + 3.15 - 0.203\sqrt{697X}$
	$(0.54X + 0.62 - 0.04\sqrt{697X})$
Diesel	$2.64X + 3.91 - 0.203\sqrt{738X+173}$
	$(0.52X + 0.77 - 0.04\sqrt{738X+173}$
LPG (liquefied petroleum gas)	$2.69X + 3.41 - 0.203\sqrt{646X}$
	$0.53X + 0.62 - 0.04\sqrt{646X}$

3.4 Oil consumption is defined as the volume per hour of engine crankcase oil replaced at the manufacturer's recommended change interval. Consumption is in L/h (gal/h), where P is the rated engine power in kW (hp).

Gasoline	0.000566P+0.02487	(0.00011P+0.00657)
Diesel	0.00059P+0.02169	(0.00021P+0.00573)
LPG (liquefied petroleum gas)	0.00041P+0.02	(0.00008P+0.00755)

4 Draft and power requirements

4.1 Draft data are reported as the force required in the horizontal direction of travel. Both functional draft (soil and crop resistance) and draft required to overcome rolling resistance of the implement are included with one exception: for manure injection, motion resistance of spreader transport wheels must be added to get total implement draft.

4.1.1 Draft force required to pull many seeding implements and minor tillage tools operated at shallow depths is primarily a function of the width of the implement and the speed at which it is pulled. For tillage tools operated at deeper depths, draft also depends upon soil texture, depth, and geometry of the tool. Typical draft requirements can be calculated as

$$D=F_i[A+B(S)+C(S)^2]WT$$

where:

D	is	implement draft, N (lbf);
F	is	a dimensionless soil texture adjustment parameter (table1);
i	=	1 for fine, 2 for medium and 3 for coarse textured soils;
A, B and C	are	machine-specific parameters (table1);
S	is	field speed, km/h (mile/h).
W	is	machine width, m (ft) or number of fows or tools (table1);
T	is	tillage depth, cm (in.) for major tools, 1 (dimensionless) for minor tillage tools and seeding implements.

Table 1 – Draft parameters and an expected range in drafts estimated by the model parameters for tillage and seeding implements

	SI Units				English Units							
		Machine Parameters				Machine Parameters			Soil Parameters			
Implement	Width units	*A*	*B*	*C*	Width units	*A*	*B*	*C*	F_1	F_2	F_3	Range ±%
MAJOR TILLAGE TOOLS												
Subsoiler/Manure Injector												
narrow point	tools	226	0.0	1.8	tools	129	0.0	2.7	1.0	0.70	0.45	50
30 cm winged point	tools	294	0.0	2.4	tools	167	0.0	3.5	1.0	0.70	0.45	50
Moldboard Plow	m	652	0.0	5.1	ft	113	0.0	2.3	1.0	0.70	0.45	40
Chisel Plow												
5 cm straight point	tools	91	5.4	0.0	tools	52	4.9	0.0	1.0	0.85	0.65	50
7.5 cm shovel/35 cm sweep	tools	107	6.3	0.0	tools	61	5.8	0.0	1.0	0.85	0.65	50
10 cm twisted shovel	tools	123	7.3	0.0	tools	70	6.7	0.0	1.0	0.85	0.65	50
Sweep Plow												
primary tillage	m	390	19.0	0.0	ft	68	5.2	0.0	1.0	0.85	0.65	45
secondary tillage	m	273	13.3	0.0	ft	48	3.7	0.0	1.0	0.85	0.65	35
Disk Harrow, Tandem												
primary tillage	m	309	16.0	0.0	ft	53	4.6	0.0	1.0	0.88	0.78	50
secondary tillage	m	216	11.2	0.0	ft	37	3.2	0.0	1.0	0.88	0.78	30
Disk Harrow, Offset												
primary tillage	m	364	18.8	0.0	ft	62	5.4	0.0	1.0	0.88	0.78	50
secondary tillage	m	254	13.2	0.0	ft	44	3.8	0.0	1.0	0.88	0.78	30
Disk Gang, Single												
primary tillage	m	124	6.4	0.0	ft	21	1.8	0.0	1.0	0.88	0.78	25
secondary tillage	m	86	4.5	0.0	ft	15	1.3	0.0	1.0	0.88	0.78	20
Coulters												
smooth or ripple	tools	55	2.7	0.0	tools	31	2.5	0.0	1.0	0.88	0.78	25
bubble or flute	tools	66	3.3	0.0	tools	37	3.0	0.0	1.0	0.88	0.78	25
Field Cultivator												
primary tillage	tools	46	2.8	0.0	tools	26	2.5	0.0	1.0	0.85	0.65	30
secondary tillage	tools	32	1.9	0.0	tools	19	1.8	0.0	1.0	0.85	0.65	25
Row Crop Cultivator												
S-tine	rows	140	7.0	0.0	rows	80	6.4	0.0	1.0	0.85	0.65	15
C-shank	rows	260	13.0	0.0	rows	148	11.9	0.0	1.0	0.85	0.65	15
No-till	rows	435	21.8	0.0	rows	248	19.9	0.0	1.0	0.85	0.65	20
Rod Weeder	m	210	10.7	0.0	ft	37	3.0	0.0	1.0	0.85	0.65	25
Disk-Bedder	rows	185	9.5	0.0	rows	106	8.7	0.0	1.0	0.88	0.78	40
MINOR TILLAGE TOOLS												
Rotary Hoe	m	600	0.0	0.0	ft	41	0.0	0.0	1.0	1.0	1.0	30
Coil Tine Harrow	m	250	0.0	0.0	ft	17	0.0	0.0	1.0	1.0	1.0	20
Spike Tooth Harrow	m	600	0.0	0.0	ft	40	0.0	0.0	1.0	1.0	1.0	30
Spring Tooth Harrow	m	2,000	0.0	0.0	ft	135	0.0	0.0	1.0	1.0	1.0	35
Roller Packer	m	600	0.0	0.0	ft	40	0.0	0.0	1.0	1.0	1.0	50
Roller Harrow	m	2,600	0.0	0.0	ft	180	0.0	0.0	1.0	1.0	1.0	50
Land Plane	m	8,000	0.0	0.0	ft	550	0.0	0.0	1.0	1.0	1.0	45
SEEDING IMPLEMENTS												
Row Crop Planter, prepared seedbed												
mounted												
seeding only	rows	500	0.0	0.0	rows	110	0.0	0.0	1.0	1.0	1.0	25
drawn												
seeding only	rows	900	0.0	0.0	rows	200	0.0	0.0	1.0	1.0	1.0	25
seed, fertilizer, herbicides	rows	1,550	0.0	0.0	rows	350	0.0	0.0	1.0	1.0	1.0	25
Row Crop Planter, no-till												
seed, fertilizer, herbicides												
1 fluted coulter/row	rows	1,820	0.0	0.0	rows	410	0.0	0.0	1.0	0.96	0.92	25
Row Crop Planter, zone-till												
seed, fertilizer, herbicides												
3 fluted coulters/row	rows	3,400	0.0	0.0	rows	765	0.0	0.0	1.0	0.94	0.82	35
Grain Drill w/press wheels												
< 2.4 m drill width	rows	400	0.0	0.0	rows	90	0.0	0.0	1.0	1.0	1.0	25
2.4 to 3.7 m drill width	rows	300	0.0	0.0	rows	67	0.0	0.0	1.0	1.0	1.0	25
> 3.7 m drill width	rows	200	0.0	0.0	rows	25	0.0	1.0	1.0	1.0	1.0	25
Grain Drill, no-till												
1 fluted coulter/row	rows	720	0.0	0.0	rows	160	0.0	0.0	1.0	0.92	0.79	35
Hoe Drill												
primary tillage	m	6,100	0.0	0.0	ft	420	0.0	0.0	1.0	1.0	1.0	50
secondary tillage	m	2,900	0.0	0.0	ft	200	0.0	0.0	1.0	1.0	1.0	50
Pneumatic Drill	m	3,700	0.0	0.0	ft	250	0.0	0.0	1.0	1.0	1.0	50

4.1.2 Typical, average draft requirement parameters are summarized in table 1 for most tillage and seeding machines. Each parameter is a function of tillage tool design. The constant parameter, A, is a function of soil strength while the coefficient of speed parameters, B or C, are related to soil bulk density. Soil is categorized as fine, medium, or coarse. Fine-textured soil is described as high in clay content, medium textured are loamy soils, and coarse textured are sandy soils. Typical values of all parameters are listed along with an expected range or variation due to differences in machine design, machine adjustment, machine age, and site-specific conditions including soil moisture and residue cover. This range gives the expected variation of average or typical draft as machine and soil conditions not included in the model vary.

4.2 Motion resistance is an additional draft force that must be included in computing implement power requirements. Values of motion resistance depend on transport wheel dimensions, tire pressure, soil type, and soil moisture. Soil moistures are assumed to be less than field capacity for implement operations. Motion resistance ratios are defined in ASAE S296 and predicted by 3.2.1.2.

4.2.1 The values given in 3.2.1 are for single wheels in undisturbed soil. For loose, tilled soils and for sands, the motion resistance ratio for a rear wheel operating in the track of a front wheel is about 0.5 of the given value. For stubble ground the value is 0.9. For firm surfaces there is no reduction.

4.2.2 Extra width of flotation tires will reduce the coefficient appreciably on soft soils but will increase it for hard soils and concrete.

4.2.3 Motion resistance ratios increase with increased tire pressure in soft soils. Doubling the tire pressure to 200 kPa causes the coefficient to increase to $-0.0135 + 1.27X$ coefficient at 100 kPa (15 lbf/in.^{2}).

4.2.4 An effective motion resistance ratio, ρ_e, can be computed for use on slopes:

$$\rho_e = \rho \cos \alpha \pm \sin \alpha$$

where:

ρ is the motion resistance ratio on level land (see 3.2.1.2);
α is the slope. The minus sign is to be used for motion down slopes.

Table 2 – Rotary power requirement parameters

Machine Type	Parameter a kW	Parameter b kW/m	Parameter c kWh/t	Parameter a hp	Parameter b hp/ft	Parameter c hph/ton	Range[1)] ±%
Baler, small rectangular	2.0	0	1.0[2)]	2.7	0	1.2[2)]	35
Baler, large rectangular bales	4.0	0	1.3	5.4	0	1.6	35
Baler, large round (var. chamber)	4.0	0	1.1	5.4	0	1.3	50
Baler, large round (fix. chamber)	2.5	0	1.8	3.4	0	2.2	50
Beet harvester[3)]	0	4.2	0	0	1.7	0	50
Beet topper	0	7.3	0	0	3.0	0	30
Combine, small grains	20.0	0	3.6[4)]	26.8	0	4.4[4)]	50
Combine, corn	35.0	0	1.6[4)]	46.9	0	2.0[4)]	30
Cotton picker	0	9.3	0	0	3.8	0	20
Cotton stripper	0	1.9	0	0	0.8	0	20
Feed mixer	0	0	2.3	0	0	2.8	50
Forage blower	0	0	0.9	0	0	1.1	20
Flail harvester, direct-cut	10.0	0	1.1	13.4	0	1.3	40
Forage harvester, corn silage	6.0	0	3.3[5)]	8.0	0	4.0[5)]	40
Forage harvester, wilted alfalfa	6.0	0	4.0[5)]	8.0	0	4.9[5)]	40
Forage harvester, direct-cut	6.0	0	5.7[5)]	8.0	0	6.9[5)]	40
Forage wagon	0	0	0.3	0	0	0.3	40
Grinder mixer	0	0	4.0	0	0	4.9	50
Manure spreader	0	0	0.2	0	0	0.3	50
Mower, cutterbar	0	1.2	0	0	0.5	0	25
Mower, disk	0	5.0	0	0	2.0	0	30
Mower, flail	0	10.0	0	0	4.1	0	40
Mower-conditioner, cutterbar	0	4.5	0	0	1.8	0	30
Mower-conditioner, disk	0	8.0	0	0	3.3	0	30
Potato harvester[3)]	0	10.7	0	0	4.4	0	30
Potato windrower	0	5.1	0	0	2.1	0	30
Rake, side delivery	0	0.4	0	0	0.2	0	50
Rake, rotary	0	2.0	0	0	0.8	0	50
Tedder	0	1.5	0	0	0.6	0	50
Tub grinder, straw	5.0	0	8.4	6.7	0	10.2	50
Tub grinder, alfalfa hay	5.0	0	3.8	6.7	0	4.6	50
Windrower/swather, small grain	0	1.3	0	0	0.5	0	40

[1)]Range in average power requirement due to differences in machine design, machine adjustment, and crop conditions.
[2)]Increase by 20% for straw.
[3)]Total power requirement must include a draft of 11.6 kN/m (±40%) for potato harvesters and 5.6 kN/m (±40%) for beet harvesters. A row spacing of 0.86 m for potatoes and 0.71 m for beets is assumed.
[4)]Based upon material-other-than-grain, MOG, throughput for small grains and grain throughput for corn. For a PTO driven machine, reduced parameter a by 10 kW.
[5)]Throughput is units of dry matter per hour with a 9 mm (0.35 in.) length of cut. At a specific throughput, a 50% reduction in the length of cut setting or the use of a recutter screen increases power 25%.

Table 3 – Field efficiency, field speed, and repair and maintenance cost parameters

Machine	Field efficiency Range %	Field efficiency Typical %	Field speed Range mph	Field speed Typical mph	Field speed Range km/h	Field speed Typical km/h	Estimated life h	Total life R&M cost % of list price	Repair factors RF1	Repair factors RF2
TRACTORS										
2 wheel drive & stationary							12 000	100	0.007	2.0
4 wheel drive & crawler							16 000	80	0.003	2.0
TILLAGE & PLANTING										
Moldboard plow	70–90	85	3.0–6.0	4.5	5.0–10.0	7.0	2 000	100	0.29	1.8
Heavy-duty disk	70–90	85	3.5–6.0	4.5	5.5–10.0	7.0	2 000	60	0.18	1.7
Tandem disk harrow	70–90	80	4.0–7.0	6.0	6.5–11.0	10.0	2 000	60	0.18	1.7
(Coulter) chisel plow	70–90	85	4.0–6.5	5.0	6.5–10.5	8.0	2 000	75	0.28	1.4
Field cultivator	70–90	85	5.0–8.0	7.0	8.0–13.0	11.0	2 000	70	0.27	1.4
Spring tooth harrow	70–90	85	5.0–8.0	7.0	8.0–13.0	11.0	2 000	70	0.27	1.4
Roller-packer	70–90	85	4.5–7.5	6.0	7.0–12.0	10.0	2 000	40	0.16	1.3
Mulcher-packer	70–90	80	4.0–7.0	5.0	6.5–11.0	8.0	2 000	40	0.16	1.3
Rotary hoe	70–85	80	8.0–14.0	12.0	13.–22.5	19.0	2 000	60	0.23	1.4
Row crop cultivator	70–90	80	3.0–7.0	5.0	5.0–11.0	8.0	2 000	80	0.17	2.2
Rotary tiller	70–90	85	1.0–4.5	3.0	2.0–7.0	5.0	1 500	80	0.36	2.0
Row crop planter	50–75	65	4.0–7.0	5.5	6.5–11.0	9.0	1 500	75	0.32	2.1
Grain drill	55–80	70	4.0–7.0	5.0	6.5–11.0	8.0	1 500	75	0.32	2.1
HARVESTING										
Corn picker sheller	60–75	65	2.0–4.0	2.5	3.0–6.5	4.0	2 000	70	0.14	2.3
Combine	60–75	65	2.0–5.0	3.0	3.0–6.5	5.0	2 000	60	0.12	2.3
Combine (SP)[1)]	65–80	70	2.0–5.0	3.0	3.0–6.5	5.0	3 000	40	0.04	2.1
Mower	75–85	80	3.0–6.0	5.0	5.0–10.0	8.0	2 000	150	0.46	1.7
Mower (rotary)	75–90	80	5.0–12.0	7.0	8.0–19.0	11.0	2 000	175	0.44	2.0
Mower-conditioner	75–85	80	3.0–6.0	5.0	5.0–10.0	8.0	2 500	80	0.18	1.6
Mower-conditioner (rotary)	75–90	80	5.0–12.0	7.0	8.0–19.0	11.0	2 500	100	0.16	2.0
Windrower (SP)	70–85	80	3.0–8.0	5.0	5.0–13.0	8.0	3 000	55	0.06	2.0
Side delivery rake	70–90	80	4.0–8.0	6.0	6.5–13.0	10.0	2 500	60	0.17	1.4
Rectangular baler	60–85	75	2.5–6.0	4.0	4.0–10.0	6.5	2 000	80	0.23	1.8
Large rectangular baler	70–90	80	4.0–8.0	5.0	6.5–13.0	8.0	3 000	75	0.10	1.8
Large round baler	55–75	65	3.0–8.0	5.0	5.0–13.0	8.0	1 500	90	0.43	1.8
Forage harvester	60–85	70	1.5–5.0	3.0	2.5–8.0	5.0	2 500	65	0.15	1.6
Forage harvester (SP)	60–85	70	1.5–6.0	3.5	2.5–10.0	5.5	4 000	50	0.03	2.0
Sugar beet harvester	50–70	60	4.0–6.0	5.0	6.5–10.0	8.0	1 500	100	0.59	1.3
Potato harvester	55–70	60	1.5–4.0	2.5	2.5–6.5	4.0	2 500	70	0.19	1.4
Cotton picker (SP)	60–75	70	2.0–4.0	3.0	3.0–6.0	4.5	3 000	80	0.11	1.8
MISCELLANEOUS										
Fertilizer spreader	60–80	70	5.0–10.0	7.0	8.0–16.0	11.0	1 200	80	0.63	1.3
Boom-type sprayer	50–80	65	3.0–7.0	6.5	5.0–11.5	10.5	1 500	70	0.41	1.3
Air-carrier sprayer	55–70	60	2.0–5.0	3.0	3.0–8.0	5.0	2 000	60	0.20	1.6
Bean puller-windrower	70–90	80	4.0–7.0	5.0	6.5–11.5	8.0	2 000	60	0.20	1.6
Beet topper/stalk chopper	70–90	80	4.0–7.0	5.0	6.5–11.5	8.0	1 200	35	0.28	1.4
Forage blower							1 500	45	0.22	1.8
Forage wagon							2 000	50	0.16	1.6
Wagon							3 000	80	0.19	1.3

[1)]SP indicates self-propelled machine.

4.3 Rotary power data are reported as functional power required at the implement engine or tractor PTO shaft. Total power is determined by adding the rotary and draft power requirements to the power required to overcome motion resistance. Typical, average rotary power requirement parameters are summarized in table 2 for 32 major types of agricultural machines. The three parameters represent the no-load power requirement, the power requirement per unit of machine operating width and the power per unit of material feed rate. Draft requirements are also noted in table 2 for root harvesting machines. Typical values of all parameters are listed along with an expected range or variation due to differences in machine design, machine condition and crop characteristics. Typical values can be adjusted within this range when conditions are likely to cause a substantial increase or decrease from the normal power requirement. Rotary power is determined using these parameters and the relationship defined in ASAE EP496, clause 4.1.2.

5 Machine performance

5.1 Performance rates for field machines depend upon achievable field speeds and upon the efficient use of time. Field speeds may be limited by heavy yields, rough ground, and adequacy of operator control. Small or irregularly shaped fields, heavy yields, and high capacity machines may cause a substantial reduction in field efficiency. Typical speeds and field efficiencies are given in table 3.

6 Costs of use

6.1 Depreciation costs are calculated using remaining value formulas estimated based on auction sale values of used farm equipment from 1984 to 1993. Calculate remaining value as a percentage of the list price for farm equipment at the end of *n* years of age and after *h* average hours of use per year using the following equation and the coefficients shown in Table 4.

$$RV_n = 100[C_1 - C_2(n^{0.5}) - C_3(h^{0.5})]^2$$

To include inflation effects, multiply the list price of farm equipment by $(1 + i)^n$ where *i* is the average annual inflation rate.

6.2 Repair and maintenance costs are highly variable and unpredictable as to time of occurrence. Surveys of accumulated repair and maintenance costs related to accumulated use do show consistent trends; however, a standard deviation equal to the mean is a typical variation in these data. Repair and maintenance factors based upon the accumulated use of the machine are given in table 3. Values listed are for machines used under typical field conditions and speeds. These data provide estimates of the average cost for all machines of a given type. The estimate is intended to be within 25% of the actual cost of maintaining most machines in good working order. Some machines may require considerably more or less repair than this estimate. A more complete description of the intended purpose and procedure for use of the data is given in ASAE EP496.

7 Reliability

7.1 Operational reliability is a probability of satisfactory machine function over any given time period. It is computed as one minus the probability of a failure.

7.1.1 Midwestern US reports by farmers (1970) of field failures show the probability of failure (tractors and implements combined) per 40 ha (100 acres) of use and the average SD of the total downtime per year for farms of over 200 ha (500 acres).

Table 4 – Remaining value coefficients

Equipment type	C_1	C_2	C_3
Farm tractors			
Small <60 kW (80 hp)	0.981	0.093	0.0058
Medium 60−112 kW (80-150 hp)	0.942	0.100	0.0008
Large >112 kW (150 hp)	0.976	0.119	0.0019
Harvest equipment			
Combines	1.132	0.165	0.0079
Mowers	0.756	0.067	–
Balers	0.852	0.101	–
Swathers and all other harvest equipment	0.791	0.091	–
Tillage equipment			
Plows	0.738	0.051	–
Disks and all other tillage equipment	0.891	0.110	–
Miscellaneous equipment			
Skid-steer loaders and all other vechicles	0.786	0.063	0.0033
Planters	0.883	0.078	–
Manure spreaders and all other miscellaneous equipment	0.943	0.111	–

	Breakdown time		Breakdown probability per 40 ha	Reliability per 40 ha
	h/yr	SD	(100 acres)	(100 acres)
Tillage	13.6	24.1	0.109	0.89
Planting corn	5.3	5.4	0.133	0.87
Planting soybeans	3.7	2.4	0.102	0.90
Row cultivation	5.6	6.3	0.045	0.96
Harvest soybeans, SP	8.2	9.6	0.363	0.64
Harvest corn, SP	12.3	12.6	0.323	0.68

7.1.2 Breakdown probabilities for machine systems increase with an increase in the size of the farm.

Crop area, ha (acres)		Probability of at least one failure per year	Reliability of tractor-machine system per year
0 to 80	(0 to 200)	0.435	0.56
80 to 160	(200 to 400)	0.632	0.30
160 to 240	(400 to 600)	0.713	0.29
240+	(600+)	0.780	0.22

7.1.3 Downtime and reliability appear to be independent of use for some machines while others have shown an increase with accumulated use. Midwestern US data show: Moldboard plows average 1 hour of downtime for each 400 ha (1000 acres) of use; row planters average 1 hour of downtime for each 250 ha (600 acres) of use; SP combines had little downtime for the first 365 ha (900 acres) of use. Downtime was a constant 1 hour for each 30 ha (70 acres) afterward; and tractors had a constantly increasing downtime rate with use. The accumulated hours of downtime depend upon the accumulated hours of use, *X*:

Spark ignition $0.0000021\ X^{1.9946}$

Diesel $0.0003234\ X^{1.4173}$

8 Working days, timeliness

8.1 Freezing temperatures, precipitation, excessive deficient soil moistures, and other weather related factors may limit field machine operations. As weather variability is great, any prediction of the number of future working days can only be made probabilistically.

8.2 The number of working days in any time period is a function of: climatic region, slope of soil surface, soil type, drainage characteristics, operation to be performed, and traction and flotation devices.

8.3 Probabilities for a working day, *pwd*, are given in table 5 for both 50% and 90% confidence levels. The probabilities obtained from the table are averages for biweekly periods. That is, a probability of 0.4 implies that 0.4×14 or 5.6 working days could be expected in that 2-week period. If the probability were taken at the 50% level, the 5.6-day figure would be exceeded in 5 years out of 10. If at the 90% level, the 5.6-day figure would be exceeded in 9 years out of 10.

8.3.1 Two types of field operations are identified soil working operations such as tillage and seeding and traffic operations where a crop is processed and the soil needs to be dry enough only to provide machine support. The Illinois and Iowa data in table 5 are reports of actual observed operations and include both types of operations. The other data are simulations for tillage operations only.

8.3.2 Dry western farms and farms under irrigation are likely to have a *pwd* approaching 1.0.

8.4 Persistence is recognized in weather data. Given that a particular day is a working day, the succeeding day has about a 0.8 (Midwest) probability of being a working day also. The probability of 5 consecutive working dates is the *pwd* for day 1 multiplied by $(0.8)^4$.

8.5 Timeliness considerations (see ASAE S495, clause 2) are important

Table 5 – Probabilities for a working day

	Region	Central Illinois		State of Iowa		Southeastern Michigan		State of South Carolina		Southern Ontario Canada		Mississippi Delta	
	Soil	Prairie soils		State average		Clay loam		Clay loam		Clay loam		Clay	
	Notes	18 yr data		17 yr data		Simulation (tillage only)		Simulation (tillage only) Sandy soils can be worked all months and have higher pwd		Simulation (tillage only) Start 7–10 days earlier on sandy soils, 0.15 greater pwd		Simulation (tillage only) Non-tillage field work pwd and pwd for sandy soils some greater in winter and early spring	
		In early spring and late fall, pwd in Iowa and Illinois may be 0.07 greater in North and West and 0.07 less in South and East											
		Probability level, percent											
Average date	Biweekly period	50	90	50	90	50	90	50	90	50	90	50	90
Jan. and Feb.	-	0.0	0.0	0.0	0.0	0.0	0.0	0.01	0.0	0.0	0.0	0.07	0.0
Mar. 7	1	0.0	0.0	0.0	0.0	0.0	0.0	-	-	0.0	0.0	-	-
Mar. 21	2	0.29	0.0	0.0	0.0	0.0	0.0	0.03	0.0	0.0	0.0	0.18	0.0
Apr. 4	3	0.42	0.13	0.39	0.16	0.0	0.0	-	-	0.01	0.0	-	-
Apr. 18	4	0.47	0.19	0.57	0.38	0.20	0.0	0.29	0.06	0.07	0.0	0.35	0.08
May 2	5	0.54	0.31	0.66	0.48	-	-	-	-	0.62	0.02	-	-
May 16	6	0.61	0.34	0.68	0.47	0.61	0.32	0.64	0.37	0.60	0.02	0.58	0.28
May 30	7	0.63	0.40	0.66	0.47	-	-	-	-	0.79	0.16	-	-
June 13	8	0.66	0.41	0.69	0.52	0.69	0.42	0.72	0.48	0.77	0.22	0.69	0.39
June 27	9	0.72	0.53	0.74	0.57	-	-	-	-	0.80	0.23	-	-
July 11	10	0.72	0.52	0.77	0.64	0.75	0.52	0.67	0.43	-	-	0.63	0.25
July 25	11	0.72	0.54	0.80	0.67	-	-	-	-	-	-	-	-
Aug. 8	12	0.78	0.64	0.80	0.68	0.74	0.53	0.73	0.51	-	-	0.72	0.45
Aug. 22	13	0.86	0.74	0.86	0.79	-	-	-	-	-	-	-	-
Sept. 5	14	0.81	0.66	0.79	0.64	0.70	0.35	-	-	-	-	-	-
Sept. 19	15	0.65	0.42	0.69	0.46	-	-	0.72	0.46	-	-	0.80	0.58
Oct. 3	16	0.72	0.52	0.71	0.48	0.59	0.26	-	-	-	-	-	-
Oct. 17	17	0.76	0.58	0.79	0.64	-	-	0.61	0.23	-	-	0.76	0.42
Nov. 1	18	0.72	0.50	0.75	0.55	0.42	0.06	-	-	-	-	-	-
Nov. 15	19	0.67	0.47	0.73	0.54	-	-	0.33	0.02	-	-	0.43	0.0
Nov. 29	20	0.54	0.43	0.82	0.70	0.07	0.0	-	-	-	-	-	-
Dec. 13	21	-	-	-	-	-	-	0.02	0.0	-	-	0.10	0.0

Adjust for Sundays and holidays by multiplying pwd's above by 0.86, 0.82, 0.78, and 0.75 for months 0, 1, 2, and 3 holidays.

to efficient selection of farm machinery. An economic value for timeliness is required to include the penalty for both quantity and quality reductions in the crop return from prolonged field machinery operations. Timeliness costs vary widely. Variation is expected among regions, crop varieties, time of the season, and machine operations. Timeliness costs are essentially zero for those tillage and other operations where there is little need to finish quickly.

8.6 A timeliness coefficient, *K* (see ASAE S495, clause 2), is a factor that permits computation of timeliness costs (see ASAE EP496, clause 8). This factor assumes linear timeliness costs with calendar days and is expressed as a decimal of maximum value of the crop per unit area per day either before or after the optimum day. These coefficients can be calculated from measured crop returns as they vary with the timing of machine operations. For example, if 10-day delay in an operation reduces the eventual return from the crop by 5%, *K* is calculated as 0.005/10 or 0.005 per unit area per day. The cost of operating on 6 ha of $100/ha crop by 7 days after the optimum would be $0.005\times6\times7\times100$=$21. (For the timeless costs for harvesting a total field, see ASAE EP496, clause 8).

8.7 Values of *K* have been determined for several operations (Table 6).

Table 6 – *K* values, derived from crop research reports

Operation	*K*
Tillage (depends on whether planting is delayed by prior tillage)	0.000-0.010
Seeding	
Corn	
Indiana, Illinois, Iowa, Eastern Nebraska, Eastern Kansas	
Available moisture in root zone at planting, cm	
10 April 0.010 May 0.000 June −0.002	
20 April 0.006 May 0.001 June −0.003	
30 April 0.003 May 0.004 June −0.007	
Wheat	
Utah	0.008
North Dakota	0.007
Soybeans	
Wisconsin, May & June	0.005
Missouri, Illinois, June	0.006
Double crop after wheat, Illinois	0.010
Cotton	
Lubbock, Texas	
April	0.004
May	0.020
Mississippi, April & May	0.007
Barley	
Utah	0.008
North Dakota	0.007
Oats	
Illinois & Michigan	0.010
Wisconsin, after May 6	0.012
Alabama, Fall	0.000
Utah	0.008
Rape	
Manitoba	0.003
Rice	
California, May	0.010
Row cultivation	
Illinois, soybeans	0.011
Rotary hoeing	
Iowa, soybeans	0.028
Harvest	
Haymaking, Michigan, June	0.018
Shelled corn, Iowa	0.003
Ear corn, Illinois, after Oct. 26	0.007
Soybeans, Illinois (depends on variety)	0.006–0.010
Wheat, Ohio	0.005
Cotton, Alabama	0.002
Rice, California	0.009
Sugar Cane, Queensland Australia	
preoptimum	0.002
postoptimum	0.003