

**ASAE EP496.2 FEB03**  
**Agricultural Machinery Management**



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# Agricultural Machinery Management

Proposed by the ASAE Farm Machinery Management Committee; approved by the Power and Machinery Division Standards Committee; adopted by ASAE December 1977 as EP391; revised editorially September 1979; reconfirmed December 1982; revised December 1983; reconfirmed December 1988; revised March 1990 and redesignated EP496; revised March 1993, March 1994; reaffirmed December 1998; revised editorially March 1999; reaffirmed December 1999, January 2001, December 2001, February 2003.

## 1 Purpose and scope

**1.1 Purpose.** This Engineering Practice is intended to provide those who manage agricultural machinery operations with assistance in using available data to determine optimum practices. It is intended that corresponding clauses in ASAE D497 be used in clauses 3, 4, 5, 6, 7, and 8 of this Engineering Practice. Terms used in this Engineering Practice are defined in ASAE S495.

**1.2 Scope.** This Engineering Practice includes information helpful in making management decisions involving machine power requirements, capacities, cost, selection, and replacement.

## 2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Engineering Practice. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Engineering Practice 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.

ASAE S296.3, *Uniform Terminology for Traction of Agricultural Tractors, Self-Propelled Implements, and Other Traction and Transport Devices*  
 ASAE S495, *Uniform Terminology for Agricultural Machinery Management*  
 ASAE D497.2 MAR94, *Agricultural Machinery Management Data*

## 3 Tractor performance

**3.1** Tractors use internal combustion engines to power farm machines. Power losses are experienced in exerting power through the drive wheels, the PTO shaft, and the hydraulic system. Figure 1 illustrates the maximum mechanical power performance expected from a two-wheel, rear axle drive tractor with rubber tires on a level concrete surface.

**3.2** Slippage of drive wheels (see ASAE S296) on soil surfaces is a power loss. This travel reduction, or slip (*s*) is measured as

$$s = \frac{(A_n - A_1)}{A_n} 100$$

where:

- s* is slip, percent;
- A<sub>n</sub>* is the advance under no load conditions per wheel or track revolution, m(ft);
- A<sub>1</sub>* is the advance under actual load conditions per wheel or track revolution, m(ft).

Expected slip values for a single-drive wheel can be calculated from ASAE D497 when the net pull and the dynamic wheel load are known.

**3.3** A drawbar power to axle power ratio, called tractive efficiency, TE, can be estimated for a complete tractor from figure 1 in ASAE D497,

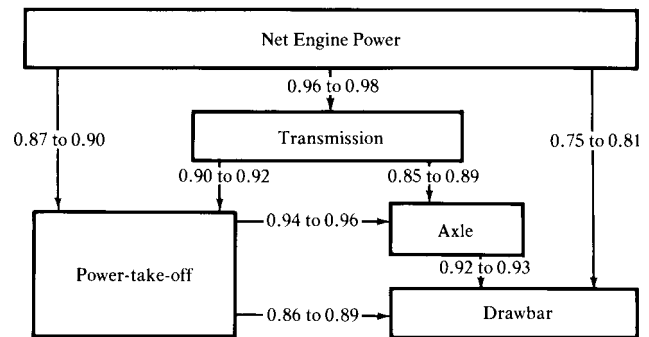


Figure 1 – Maximum mechanical power performance expected

when the slip is known. Maximum TE is obtained with optimum slip ranges of:

- 4–8% for concrete;
- 8–10% for firm soil;
- 11–13% for tilled soil;
- 14–16% for soft soils and sands.

TE (and tire efficiency) of a single-drive wheel can be predicted from ASAE D497, clause 3. The performance of a tractor is made up of the sum of the individual wheel performances. For a two-wheel rear drive tractor, the motion resistances of the front wheels subtract from the net pulls obtained from the two-drive wheels to produce the net tractor drawbar pull.

## 4 Power requirement

### 4.1 Implement (machine) power components

**4.1.1** Drawbar power is power transferred through the drive wheels or tracks to move the tractor and/or implement through or over the crop or soil. Draft is the total force parallel to the direction of travel required to propel the implement. It is the sum of the soil and crop resistance and the implement motion resistance.

$$D = R_{sc} + MR$$

where:

- D* is implement, draft, *N* (lbf);
- R<sub>sc</sub>* is soil and crop resistance, *N* (lbf);
- MR* is total implement motion resistance, *N* (lbf).

**4.1.1.1** Soil and crop resistance is the force parallel to the direction of travel resulting from the contact between the soil or crop and the working components of the implement. Typical values of unit soil and crop resistance forces are given in ASAE D497, clause 4. Soil and crop resistance for an implement is computed as

$$R_{sc} = nr_{sc}$$

where:

- R<sub>sc</sub>* is soil and crop resistance for the implement, *N* (lbf);
- n* is implement numeric consisting of total width, number of shanks, cross-sectional area, number of rows, etc., as required to balance the units of the equation and depending on the units of *r<sub>sc</sub>*;

Table 1 – Average unit accumulated costs

End of year	Remaining value	R&M costs	Depr.	Int.	Acc. depr.	Acc. int.	Acc. R&M	Tot. acc. costs, \$	Acc. use, ha	Unit acc. costs, \$/ha
1	2000	10	1000	200	1000	200	10	1210	100	12.10
2	1400	50	600	136	1600	336	60	1996	200	9.98
3	1000	70	400	96	2000	432	130	2562	300	8.54
4	700	100	300	68	2300	500	230	3030	400	7.58
5	500	200	200	48	2500	548	430	3478	500	6.96
6	350	300	150	34	2650	582	730	3962	600	6.60
7	225	350	125	23	2775	605	1080	4460	700	6.37
8	125	450	100	14	2875	619	1530	5024	800	6.28
9	100	550	25	9	2900	628	2080	5608	900	6.23
10	75	600	25	7	2925	635	2680	6240	1000	6.24

$r_{sc}$  is unit soil and crop resistance specific to the implement, as given in ASAE D497, clause 4. This value is the soil and crop resistance (also called functional draft) of the implement parallel to the direction of travel. This value does not include motion resistance. Units depend on the specific implement, and must balance the units of  $n$ .

4.1.1.2 Motion resistance (see ASAE S296) becomes appreciable when heavy implements are used in soft or loose soils. Values for the motion resistance ratio are predicted by ASAE D497, clause 3. Tire parameters and wheel loadings must be known or assumed. Total implement motion resistance is computed as

$$MR = \sum R_M$$

where:

$MR$  is the total implement motion resistance,  $N$  (lbf);  
 $R_M$  is motion resistance of each individual wheel supporting the implement,  $N$  (lbf).

The motion resistance of each individual wheel can be computed as

$$RM = 9.8 \rho m$$

where:

$\rho$  is motion resistance ratio (no units);  
 $m$  is dynamic wheel load, kg;

or,

$$RM = \rho m$$

where:

$\rho$  is motion resistance ratio (no units);  
 $m$  is dynamic wheel load, lb.

4.1.1.3 Drawbar power for tractor-powered implements (and propulsion power for self-propelled implements) is computed as

$$P_{db} = \frac{Ds}{3.6}$$

where:

$P_{db}$  is drawbar power required for the implement, kW;  
 $D$  is implement draft, kN;  
 $s$  is travel speed, km/h;

or,

$$P_{db} = \frac{Ds}{375}$$

where:

$P_{db}$  is drawbar power required for the implement, hp;  
 $D$  is implement draft, lb;  
 $s$  is travel speed, mph.

4.1.2 Power-takeoff, PTO, power is power required by the implement from the PTO shaft of the tractor or engine. Typical PTO power requirements can be determined using rotary power requirement parameters given in ASAE D497, clause 4. Implement power take-off power can be calculated as

$$P_{pto} = a + bw + cF$$

where:

$P_{pto}$  is power-takeoff power required by the implement kW (hp);  
 $w$  is implement working width, m (ft);  
 $F$  is material feed rate, t/h(ton/h) wet basis;  
 $a$ ,  $b$ , and  $c$  are machine specific parameters (ASAE D497, table 1).

4.1.3 Hydraulic power is the fluid power required by the implement from the hydraulic system of the tractor or engine. Implements hydraulic power can be computed as

$$P_{hyd} = \frac{\rho F}{1000}$$

where:

$P_{hyd}$  is hydraulic power required by the implement, kW;  
 $F$  is fluid flow, L/s;  
 $\rho$  is fluid pressure, kPa;

or,

$$P_{hyd} = \frac{\rho F}{1714}$$

where:

$P_{hyd}$  is hydraulic power required by the implement, hp;  
 $F$  is fluid flow gal/min;  
 $\rho$  is fluid pressure, psi.

4.1.4 Electric power is required to operate components of some implements. To compute implement electric power

$$P_{el} = \frac{IE}{1000}$$

where:

$P_{el}$  is electric power required by the implement, kW;  
 $I$  is electric current, A;  
 $E$  is electric potential, V;

or,

$$P_{el} = \frac{IE}{746}$$

where:

$P_{el}$  is electric power required by the implement, hp;  
 $I$  is electric current, A;  
 $E$  is electric potential, V;

**4.2** Total power requirement for operating implements (drawn or self-propelled) is the sum of implement power components converted to equivalent PTO power. Total implement power requirement can be computed as

$$P_T = \frac{P_{db}}{E_m E_t} + P_{pto} + P_{hyd} + P_{el}$$

where:

$P_T$  is total implement power requirement, kW (hp);  
 $E_t$  is traction efficiency (expressed as a decimal) (see ASAE D497, clause 3);  
 $P_{db}$  is drawbar power required for the implement, kW (hp);  
 $P_{hyd}$  is hydraulic power required by the implement, kW (hp);  
 $P_{pto}$  is power-takeoff power required by the implement, kW (hp);  
 $P_{el}$  is electric power required by the implement, kW (hp);  
 $E_m$  is mechanical efficiency of the transmission and power train.  
 This coefficient is typically 0.96 for tractors with gear transmissions.

**4.3** Total engine power must be greater than the total implement power required. Additional power is required to accelerate and overcome changes in topography, soil and crop conditions. Additional power is also required for operator-related equipment such as hydraulic control systems, air conditioning, etc.

## 5 Field machine performance

**5.1** Field efficiency (see ASAE S495) is the ratio between the productivity of a machine under field conditions and the theoretical maximum productivity. Field efficiency accounts for failure to utilize the theoretical operating width of the machine; time lost because of operator capability and habits and operating policy; and field characteristics. Travel to and from a field, major repairs, preventive maintenance, and daily service activities are not included in field time or field efficiency. Field efficiency is not a constant for a particular machine, but varies with the size and shape of the field, pattern of field operation, crop yield, moisture, and crop conditions. The following activities account for the majority of time lost in the field:

- turning and idle travel;
- materials handling;
  - seed;
  - fertilizer;
  - chemicals;
  - water;
  - harvested material;
- cleaning clogged equipment;
- machine adjustment;
- lubrication and refueling (besides daily service);
- waiting for other machines.

**5.2** Effective field capacity is a function of field speed, machine working width, field efficiency, and unit yield of the field. Area capacity is expressed as

$$C_a = \frac{swE_f}{10}$$

where:

$C_a$  is area capacity, ha/h;  
 $s$  is field speed, km/h;  
 $w$  is implement working width, m;  
 $E_f$  is field efficiency, decimal;

or,

$$C_a = \frac{swE_f}{8.25}$$

where:

$C_a$  is area capacity, acre/h;  
 $s$  is field speed, mile/h;  
 $w$  is implement working width, ft;  
 $E_f$  is field efficiency, decimal.

Material capacity is expressed as

$$C_m = \frac{swyE_f}{10}$$

where:

$C_m$  is material capacity, t/h;  
 $s$  is field speed, km/h;  
 $w$  is implement working width, m;  
 $E_f$  is field efficiency, decimal;  
 $y$  is unit yield of the field, t/ha;

or,

$$C_m = \frac{swyE_f}{8.25}$$

where:

$C_m$  is material capacity, ton/acre;  
 $s$  is field speed, mile/h;  
 $w$  is implement working width, ft;  
 $E_f$  is field efficiency decimal.  
 $y$  is unit yield of the field, ton/acre.

Typical ranges of field efficiency and field speed can be found in ASAE D497, clause 5. Theoretical field capacity can be determined by using a field efficiency of 1.0.

**5.3** The ability of a manager to make good use of personal working hours and those of employees if evaluated as scheduling efficiency. For example, if a workday is 10 h long and 8 h are used effectively, the scheduling efficiency is 80%. Ineffective scheduling requires larger capacity machines than are really necessary and increases capital investment.

**5.4** Performance of machines operated by ground wheel drives depends on the amount of slippage experienced between the tire and the ground surface. A correction for slippage may be needed to predict performance of planters, grain drills, and other metering and rate application machines.

## 6 Cost of use

**6.1 Cost factors.** The total cost of using a field machine includes charges for ownership and operation. Ownership costs are seemingly

independent of use and are often called fixed costs or overhead costs. Costs for operation vary directly with the amount of use and are often called variable costs.

## 6.2 Ownership costs

**6.2.1 Depreciation.** This cost reflects the reduction in value of an asset with use and time. The actual total depreciation can never be known until the equipment has been sold; however, an estimated depreciation can be predicted from any of several methods. Different computational methods are used depending upon the objective. (For more detailed information consult an engineering economics textbook.)

**6.2.1.1** To predict costs for crop production accounting, depreciation may be spread evenly over the accumulated use of the equipment in hectares (acres) or hours. Simple annual depreciation is determined by subtracting the salvage value from the purchase price and dividing by the anticipated length of time owned.

**6.2.1.2** A current market value helps estimate depreciation. Several publications report such values; examples include: Official Guide Tractors and Farm Equipment and Farm Equipment Guide, Monthly Update. These on-farm remaining values are approximated as percentages of the list price for the end of each year (see ASAE D497, clause 6). Inflation and equipment shortages and surpluses in the market place cause wide variation in these predicted remaining values. The price of used equipment after being reconditioned by a dealer may be 1.3 times the on-farm value.

**6.2.2 Interest.** An interest charge for the use of the money in a machine investment is an ownership cost. Simple interest on the average investment over the life of the machine can be added to the annual depreciation to estimate the yearly capital costs of ownership (see clause 6.2.4). A method for determining the capital costs of ownership which includes the time value of money makes use of a Capital Recovery Factor, CRF. The investment in the machine is multiplied by the proper CRF to give a series of equal payments over the life of the machine which includes both the cost of depreciation and interest.

$$R = (P - S) \left[ \frac{\left( \frac{i}{q} \right) \left( 1 + \frac{i}{q} \right)^{nq}}{\left\{ \left( 1 + \frac{i}{q} \right)^{nq} \right\} - 1} \right] + \frac{Si}{q}$$

where:

- $R$  is one of a series of equal payments due at the end of each compounding period,  $q$  times per year;
- $P$  is principal amount;
- $i$  is interest rate as compounded  $q$  times per year;
- $n$  is life of the investment in years;
- $S$  is salvage value.

**6.2.3 Other ownership costs.** Taxes, housing, and insurance can be estimated as percentages of the purchase price. If the actual data are not known, the following percentages can be used:

- taxes 1.00;
- housing 0.75;
- insurance 0.25;
- total 2.00% of purchase price.

**6.2.4 Total annual ownership costs.** A simple estimate of total annual ownership costs is given by multiplying the purchase price of the machine by the ownership cost percentage. The ownership cost percentage can be calculated as

$$C_o = 100 \left[ \frac{1 - S_v}{L} + \frac{1 + S_v}{2} I + K_2 \right]$$

where:

- $C_o$  is ownership cost percentage. This value (when expressed in decimal form) multiplied by the machine purchase price yields the average annual total ownership cost of the machine;
- $S_v$  is salvage value factor of machine at end of machine life (year  $L$ ), decimal;
- $L$  is machine life, yr;
- $I$  is interest rate, decimal;
- $K_2$  is ownership cost factor for taxes, housing, and insurance; normally expressed as a percentage of the purchase price, but expressed in decimal form in this equation.

## 6.3 Operating costs

**6.3.1 Repair and maintenance.** Expenditures are necessary to keep a machine operable due to wear, part failures, accidents, and natural deterioration. The costs for repairing a machine are highly variable. Good management may keep costs low. Indices of repair and maintenance costs are shown in ASAE D497, clause 6. The size of the machine, as reflected by its list price, and the amount of use are factors affecting the costs. Both the use and costs are expressed in an accumulated mode to reduce variability. In times of rapid inflation, the list price must be increased to reflect inflation effects. Accumulated repair and maintenance costs at a typical field speed can be determined with the following relationship using the repair and maintenance factors RF1 and RF2 (see ASAE D497, clause 6) and the accumulated use of the machine:

$$C_{rm} = (RF1) P \left[ \frac{h}{1000} \right]^{(RF2)}$$

where:

- $C_{rm}$  is accumulated repair and maintenance cost, dollars;
- RF1 and RF2 are repair and maintenance factors (see ASAE D497, clause 6);
- $P$  is machine list price in current dollars. In times of rapid inflation, the original list price must be multiplied by  $(1 + i)^n$  where  $i$  is the average inflation rate and  $n$  is the age of the machine;
- $h$  is accumulated use of machine, h.

This relationship provides an estimate of the total costs of all replacement parts, materials, shop expenses, and labor for maintaining a machine in good working condition. Actual costs may vary widely due to differences in machine maintenance, management, and quality. Data should not be extrapolated beyond the estimated life of the machine. Estimated life is the level of accumulated use where further repair of the machine is normally not justified. For machines used beyond the estimated life, accumulated repair and maintenance costs can be assumed to increase at a constant rate equal to the rate at the end of its estimated life. As an example of the use of these indices, the accumulated repair and maintenance costs for a \$12,000 mower-conditioner used 1200 h would be:

$$C_{rm} = (0.18)(12000) \left( \frac{1200}{1000} \right)^{1.6}$$

where:

- $C_{rm}$  is \$2891 for an average-to-date cost of \$2.41/h.

## 6.3.2 Fuel

**6.3.2.1 Average fuel consumption for tractors.** Annual average fuel requirements for tractors may be used in calculating overall machinery costs for a particular enterprise. However, in determining the cost for a particular operation such as plowing, the fuel requirement should be based on the actual power required.

**6.3.2.1.1** Average annual fuel consumption for a specific make and model tractor can be approximated from the Nebraska Tractor Test Data. Average gasoline consumption over a whole year can be estimated by the following formula:

$$Q_{avg} = 0.305 \times P_{pto}$$

where:

$Q_{avg}$  is average gasoline consumption, L/h;

$P_{pto}$  is maximum PTO power, kW;

or,

$$Q_{avg} = 0.06 \times P_{pto}$$

where:

$Q_{avg}$  is average gasoline consumption, gal/h;

$P_{pto}$  is maximum PTO power, hp.

**6.3.2.1.2** A diesel tractor will use approximately 73% as much fuel in volume as a gasoline tractor, and liquefied petroleum LP, gas tractors will use approximately 120% as much.

**6.3.2.1.3** Fuel consumption for engines not included in the Nebraska Tractor Test Data may be estimated by the above formula by substituting the advertised PTO power, kW (hp), for the maximum PTO power, kW (hp), or by comparing them with a tractor engine of similar displacement.

**6.3.2.2 Fuel consumption for a specific operation.** Predicting fuel consumption for a specific operation requires determination of the total tractor power for that operation (see clause 4). The equivalent PTO power is then divided by the rated maximum to get a percent load for the engine. The fuel consumption at that load is obtained from ASAE D497, clause 3. Fuel consumption for a particular operation can be estimated by the following calculation:

$$Q_i = Q_s P_T$$

where:

$Q_i$  is estimated fuel consumption for a particular operation L/h (gal/h);

$Q_s$  is specific fuel consumption for the given tractor, determined from ASAE D497, clause 3, L/kW h (gal/hp-h);

$P_T$  is total tractor power (PTO equivalent) for the particular operation kW (hp).

A fuel consumption of 15% above that for Nebraska Tractor Tests is included for loss of efficiency under field conditions.

**6.3.3** Engine oil consumption is based on 100-h oil change intervals. The consumption rate of oil ranges from 0.0378 to 0.0946 L/h (0.01 to 0.025 gal/h) depending upon the volume of the engine's crankcase capacity. If oil filters are changed every second oil change, total engine lubrication cost approaches 15% of total fuel cost. Usually the cost of filters and the cost of oil other than crankcase oil is included as maintenance cost. For oil consumption as related to engine size ASAE D497, clause 3.

**6.3.4 Labor cost.** The cost of labor varies with geographic location. For owner-operators, labor cost should be determined from alternative opportunities for use of time. For hired operators, a constant hourly rate is appropriate. In no instance should the charge be less than a typical, community labor rate.

**6.3.5** A portion of the tractor ownership costs must be included in the cost of use of implements. Tractor ownership costs are recovered by assessing those operations that use the tractor. Assessing may be done on an energy use basis, but is more commonly done on a time basis. For example: If a tractor has \$1000 of ownership costs per year and is used 500 h annually, a \$2 charge is made against the implement operation for each hour the tractor powers the implement. Implements not using a tractor (self-propelled) do not have such a cost.

## 7 Reliability

**7.1** Operational reliability is defined as the statistical probability that a machine will function satisfactorily under specified conditions at any given time. The operational reliability is computed as one minus the probability for downtime when both probabilities are in decimal form. The reliability probability for the next minute of machine operation is essentially one, but decreases when the time span under consideration lengthens. The probability of having a complex machine continually operational for several seasons on a large farm is essentially zero.

**7.2** The reliability of a combination of components or machines is the product of the individual probabilities. Complex machines with many components must have very high individual component reliabilities to achieve satisfactory operational reliability.

**7.3** Surveys of field breakdowns as reported in ASAE D497, clause 7, indicate expected reliability for several field operations.

## 8 Selection of field machine capacity

**8.1** Simple capacity selection is made by estimating the number of days in the time span within which the operation should be accomplished, and by determining the probability of a working day in this time span (see ASAE D497). The required capacity for an area is

$$C_i = \frac{A}{BG(\text{pwd})}$$

where:

$C_i$  is required machine capacity, ha/h (acre/hr);

$A$  is area, ha (acre);

$B$  is number of days within the time span within which the operation should be accomplished, day;

$G$  is expected time available for field work each day, h/day;

pwd is the probability of a working day, decimal.

**8.2** Economic selection finds that capacity which produces the lowest net cost. The increased ownership costs of high capacity machines are balanced against the increased operation costs and timeliness costs of low capacity machines.

**8.2.1** A unit price function must be determined which reflects the increased price of one unit of increased capacity. On many machines, the price of a unit increase in effective width is linear and directly related to price per capacity. The unit price function can be calculated as follows:

$$K_p = \frac{10P_w}{sE_f}$$

where:

$K_p$  is the unit price function which reflects the increased price of one unit of increased capacity, dollars/ha-h;

$s$  is field speed, km/h;

$P_w$  is price per unit width of increased width of machine, dollars/m;

$E_f$  is field efficiency, decimal;

or,

$$K_p = \frac{8.25P_w}{sE_f}$$

where:

$K_p$  is unit price function which reflects the increased price of one unit of increased capacity, dollars/acre-h;

$s$  is field speed, mph;

$P_w$  is price per unit width of increased width of machine, dollars/ft;

$E_f$  is field efficiency, decimal.

**8.2.2** If fuel, oil, and repair and maintenance costs can be assumed to be functions of field area covered, they are not pertinent to the selection

problem and can be ignored. Only a labor cost,  $L_c$ , dollars/h, and a tractor ownership cost,  $T_{fc}$ , dollars/h, are important to the operations costs.  $T_{fc}$  equals zero for self-propelled machines.

**8.2.3** The timeliness cost is estimated from a timeliness coefficient obtained from ASAE D497, clause 8. The annual timeliness cost for an operation can be estimated by

$$W = \frac{K_3 A^2 Y V}{Z G C_i (\text{pwd})}$$

where:

- $W$  is annual timeliness cost, dollars;
- $K_3$  is timeliness coefficient obtained from ASAE D497, clause 8;
- $A$  is area, ha (acre);
- $Y$  is yield per area, t/ha (ton/acre);
- $V$  is value per yield, dollars/t (dollars/ton);
- $Z$  is 4 if the operation can be balanced evenly about the optimum time, and a value of 2 if the operation either commences or terminates at the optimum time;
- $G$  is expected time available for field work each day, h;
- pwd is probability of a working day, decimal;
- $C_i$  is machine capacity, ha/h (acre/h).

**8.2.4** The optimum capacity of a machine can be estimated from the first differential of the annual cost with respect to the machine capacity

$$M_{oc} = \sqrt{\frac{100A}{C_o K_p} \left( L_c + T_{fc} + \frac{K_3 A Y V}{Z G (\text{pwd})} \right)}$$

where:

- $M_{oc}$  is optimum capacity of a machine, ha/h (acre/h);
- $A$  is area, ha (acre);
- $C_o$  is ownership cost percentage, percent;
- $K_p$  is unit price function, dollars/ha-h (dollars/acre-h);
- $L_c$  is labor cost, dollars/ha (dollars/acre);
- $T_{fc}$  is tractor ownership cost, dollars/ha (dollars/acre);
- $K_3$  is timeliness coefficient obtained from ASAE D497, clause 8;
- $A$  is area, ha (acre);
- $Y$  is yield per area, t/ha (ton/acre);
- $V$  is value per yield, dollars/t (dollars/ton);
- $Z$  is 4 if the operation can be balanced evenly about the optimum time, and a value of 2 if the operation either commences or terminates at the optimum time;
- $G$  is expected time available for field work each day, h;
- pwd is probability of a working day, decimal.

As an example, consider the required capacity for a field cultivator having a unit price function of \$400 per ha per h, a 16% ownership cost percentage, used on 200 ha twice each year. Labor and tractor ownership costs per ha are \$3 each. The crop has a value,  $YV$ , of \$150 per ha, and there are 10 field working hours per day at a probability of 0.8. The operations will be balanced about the optimum time ( $Z = 4$ ) and the value of  $K_3$  is selected as 0.0002.

$$M_{oc} = \sqrt{(2) \left\{ \frac{(100)(200)}{(16)(400)} \left[ 3 + 3 + \frac{(0.0002)(200)(150)}{(4)(10)(0.8)} \right] \right\}}$$

$$= 6.2 \text{ ha/h}$$

If field speed is expected to be 8 km/h and the field efficiency 0.80, the width of the field cultivator would be

$$C_a = \frac{sWE_f}{10}$$

$$6.2 = \frac{(8)(W)(0.80)}{10}$$

∴ width is 9.7 m.

**8.3** The selection of a machine system involves the selection of tractors and their associated machines which give least cost when both timeliness and scheduling factors are considered. Except for the simplest of systems, such selections are accomplished with digital computer programs.

## 9 Replacement

**9.1** Machines employed in production may need to be replaced for one or more reasons.

**9.1.1** A machine suffers accidental damage such that the cost of renewal is so great that a new machine is more economical.

**9.1.2** The capacity of the existing machine is inadequate because of increased scale of production.

**9.1.3** The machine is obsolete (see ASAE S495).

**9.1.4** The machine is not expected to operate reliably. (Suffers considerable unanticipated downtime from random part failures).

**9.1.5** The cost of making an anticipated repair would increase the average unit accumulated cost (see ASAE S495) above the expected minimum. Only capital costs and actual repair and maintenance costs need be accumulated. For example, a \$3000 machine is used 100 ha annually. It experiences the following end-of-year depreciation, interest (8% simple interest on average investment), and actual repair and maintenance costs listed in table 1. Year 9 has the lowest unit cost and indicates the machine should be replaced with a similar machine at the end of year 9 if not before for other reasons. Inflation effects must be considered in making replacement decisions. Annual depreciation charges may be quite low or even negative in times of rapid inflation producing a premature minimum unit accumulated cost. In such instances replacement is better indicated by comparing the unit accumulated cost of the present machine with the projected costs for a potential successor machine. Optimum replacement time may be delayed beyond that time determined under more stable economic conditions.

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## Annex A (informative) Bibliography

The following documents are cited as reference sources used in development of this Engineering Practice:

*Farm Equipment Guide, Monthly Update*. Fort Dodge: Hot Line, Inc.

*Nebraska Tractor Test Data*. Lincoln: Univ. of Nebraska Agr. Eng. Dept.

*Official Guide-Tractors and Farm Equipment*. St. Louis: North American Equipment Dealers Assn.