Elements of design and evaluation of animal-drawn weeders

by

Brian G Sims

Silsoe Research Institute, Silsoe, Bedford, MK45 4HS, UK

Abstract

The influence of soil parameters and weeder design on implement performance is discussed. Soil parameters that are important in this context are cohesion, adhesion and internal friction. Important weeder design parameters are blade angles of attack and approach, blade overlap and blade support configuration. An example of an animal-drawn weeder developed in Mexico is analysed.

An evaluation of weeder performance will depend on the categories of information required for a particular purpose and should include both technical and socio-economic parameters. Evaluation parameters discussed are: soil type and condition; crop and weed type and population; effectiveness of weed control; crop damage; implement draft, forward speed and power requirement; working width and speed; theoretical and actual field capacity, field efficiency; durability; ergonomic and economic appraisals.

Introduction

Weed control is often the most important agricultural task facing farmers in developing countries. Manual weeding can be very demanding of labour: de Datta et al, cited by Tewari, Datta and Murthy (1993), quoted figures of 300–1200 hours/ha for India; Sims et al (1987) reported that Mexican smallholder farmers, using both human and animal power, devoted about a quarter of their labour input to weeding. In both cases weeding took place during peak labour demand seasons, and could be the factor limiting the area cultivated by farm families.

Considerable effort has been invested in developing alternatives to traditional smallholder weeding technologies (including human and engine or electrically powered technologies), but the innovations have not always been greeted with enthusiasm by the intended clientele (the farmers). The process of technology development ought, usually, to take as a starting point the requirements of the farm family. Given that a need exists, then the technical and economic constraints imposed on potential designs by the farming systems should be taken into account.

Assuming that this process has been followed, design criteria will then be considered and prototypes designed, fabricated and evaluated. This paper presents some of the more important elements to be considered in the design and evaluation of animal-drawn special-purpose mechanical weeders. It is aimed at designers and testers of farm machinery principally for the small-farm sector.

Design considerations

The performance of a weeder will depend on:

- the condition of the crop and weed population
- soil characteristics
- the characteristics of the interface between soil and the soil acting elements of the weeder
- weeder design parameters.

In the particular case of animal-drawn weeders, the implement draft and the capacity of the animals to provide the required power will also affect performance, as will ergonomic considerations related to the comfort of the operator.

In this section—which draws on Spoor (1969) as a guide—the influence of soil parameters, soil/weeder material (usually metal) parameters and weeder design are discussed.

Soil parameters

When soil-acting mechanical weed-control implements are used, the soil is subjected to cutting or shear forces which cause it to fail and disintegrate. The parameters which influence a soil's resistance to this failure are:

- its cohesion (c)
- its internal friction, described by the angle of internal friction (ϕ)

This paper is published in: Starkey P and Simalenga T (eds), 2000. *Animal power for weed control.* A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA). Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, The Netherlands. ISBN 92-9081-136-6. For details of ATNESA and its resource publications see **http://www.atnesa.org**

Micklethwaite, quoted by Ashburner and Sims (1984), expressed the relation between the force required to shear a soil, its cohesion and its angle of internal friction as follows:

H_{max} = cA + W tan (1)

where:

H_{max} = maximum shear force
A = area of soil sheared
W = normal loading on the soil

From equation (1) it can be appreciated that in a highly cohesive soil (eg, a clay soil in a plastic state), the area of soil sheared (A) is more important than the normal load (W) in determining the force needed for failure to occur. On the other hand, a frictional soil (eg, a dry sand with a very low clay content), offers greater resistance to failure when the normal load is increased. The vast majority of agricultural soils display both cohesive and frictional properties.

Resistance to the implement

In addition to the soil parameters that are brought into play by soil/soil shear failure, the movement of the soil acting elements of a weeder (usually tines of some sort) through the soil is affected by:

- adhesion of the soil/material (usually steel) interface (c)
- friction between soil and metal, described by the angle of soil/metal friction ( )

The relation between the resistance to soil sliding over the metal surface can be represented by an equation similar to that used to describe soil/soil resistance:

H'_{max} = c A + W tan (2)

where:

H'_{max} = the maximum soil/metal sliding force
A = area of metal in contact with the soil
W = normal loading of the soil on the metal

Equation (2) shows the importance of reducing the surface area (A) of the implement in contact with adhesive soils (eg, a clay soil in a plastic state). The angle of soil/metal friction is influenced by the cleanliness of the implement surfaces in contact with the soil and is dramatically increased by oxidation (rust).

Angle of attack

The angle of inclination (or angle of attack) of a weeder tine has two important effects:

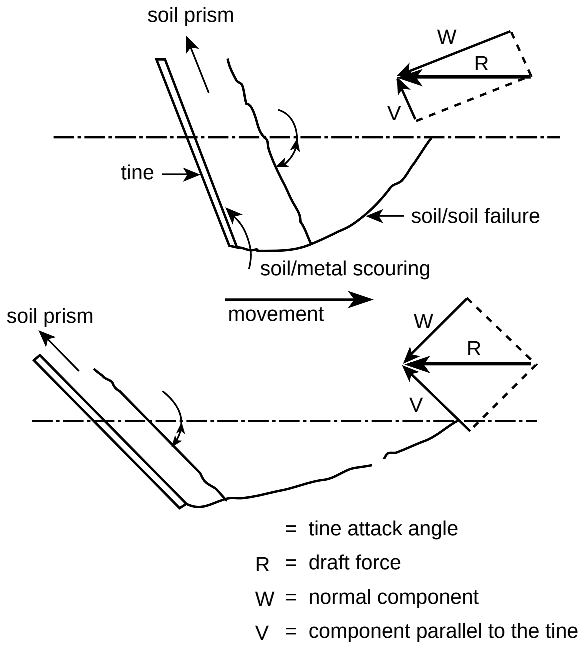


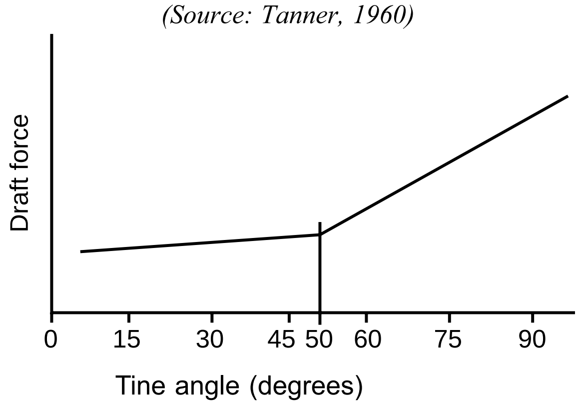
Figure 1: Effect of a reduction of the angle of attack of a tine on soil/metal scouring. Reducing the angle (α) will reduce the normal force (W) and, consequently, the frictional component of H' . (Source: Payne and Tanner, 1959)

- it affects the ease of scouring of soil over the tine (Payne and Tanner, 1959)
- it affects the draft force needed to move the tine through the soil (Tanner, 1960).

Reducing the angle of attack of a tine will reduce the normal force (W) acting on it, reducing the frictional component of H' and consequently the scouring resistance (Figure 1).

The important effect of tine attack angle on draft force is indicated in Figure 2. Draft force increases slowly for angles in the range 10–50°; at larger angles the draft force increases more rapidly. An attack angle of about 15° will produce good scouring with minimum draft force.

Figure 2: Effect of tine angle on draft force required (Source: Tanner, 1960)



Weeder design

In this section some aspects of weeder design which have an influence on field performance are discussed. The parameters analysed are tine attack and approach angles, tine overlap and tine support design.

Tine angles

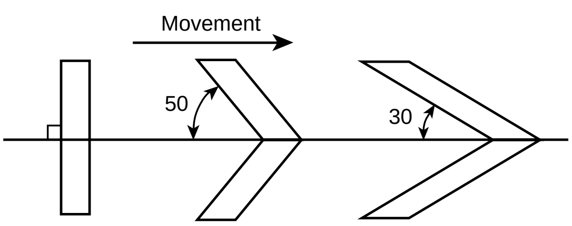
Mechanical weeders will often be designed to cut the soil beneath weeds with a superficial root system, or to cut through the roots of weeds with a deep system.

For weeds with a superficial root system the plants need to be lifted to the soil surface and separated from the soil so that they dry out. The implement indicated for this task is a wide tine with an attack angle that will lift weeds without mixing them with soil.

An angle of attack of approximately 15° is ideal to lift and separate the weeds from the soil (Chase, 1942). At greater angles the tine starts to act like a bulldozer, which tends to leave the weeds mixed with soil. An angle of less than 15° may not have sufficient lifting action and would leave the weeds in their original positions.

In the case of deep rooted weeds, it is necessary to cut these and ensure that the vegetation does not become wrapped around the tines. Theoretically an approach angle of 90° would effect a complete cut of all the roots. However, when working near the soil surface with an attack angle of 15°, blade penetration may be difficult, especially in hard soils. On the other hand, if the plants are not firmly anchored, they will not be completely severed by the blade. With a reduced approach angle, less than 30°, soil penetration will be improved. However, the weeds will have a tendency to bend around the edges of the tine without being cut.

Figure 3. Approach angle of a weeder tine. A 90° angle makes penetration difficult; 50° is recommended in friable soils with a low weed population; 30° for hard soils with abundant vegetation. (Source: Spoor, 1969)



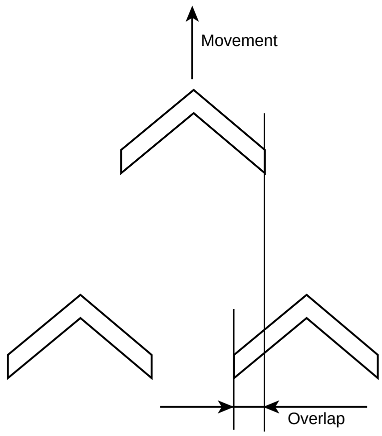


Figure 4: Overlap for weeder tines. Recommended values are: 40 mm for easy conditions, increasing to 100 mm for tough weeds

As a guide, approach angles of 30–50° are recommended; the angle can be greater in loose soil with a low weed population. The principle is illustrated in Figure 3.

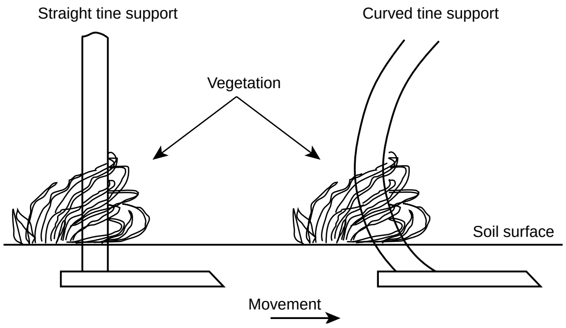
In order to minimise the possibility of leaving uncut weeds, the tines are overlapped (see Figure 4).

Tine support design

A tine support which allows vegetation to accumulate over the soil will produce a surcharge ('W' in equations 1 and 2) which will increase the draft force required to pull the implement. A curved support (see Figure 5) keeps any accumulated vegetation away from the soil failure zone.

To promote a good flow of material around the supports, they should have the maximum possible clearance between themselves and give the maximum clearance between the soil and the weeder main frame.

Figure 5. Tine support design. A straight support does not allow vegetation to be lifted away from the soil failure zone and results in a surcharge. A curved support will improve the situation



This paper is published in: Starkey P and Simalenga T (eds), 2000. *Animal power for weed control.* A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA). Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, The Netherlands. ISBN 92-9081-136-6. For details of ATNESA and its resource publications see **http://www.atnesa.org**

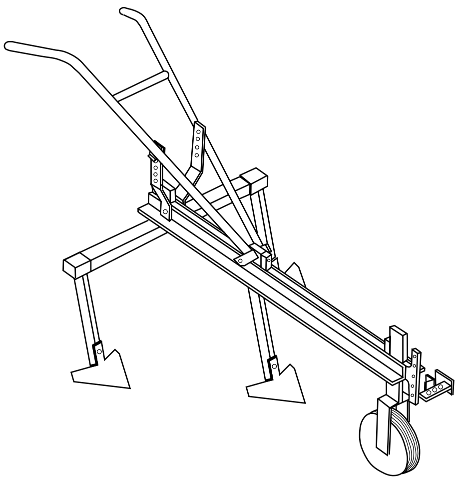


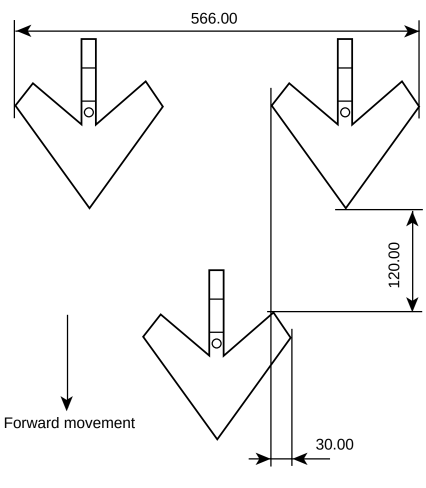
Figure 6. A multi-purpose toolbar fitted with three weeder tines. (Source: Sims, 1987)

An example analysed

In a series of evaluations of animal-drawn weeders developed and manufactured in Mexico (in collaboration with Alan Stokes, Project Equipment, Oswestry, UK), the configuration of each implement was examined. One example (Figure 6) was a multipurpose toolbar with three 'A' shares on rigid supports. The tine configuration and overlap is shown in Figure 7 and the angles of attack and approach are shown in Figure 8.

The attack angle of 28° is high for hard soil conditions but will provoke good soil disintegration in friable conditions. The approach angle of 72° can also be expected to give problems of penetration in hard soils. Tine overlap is 30 mm, on the low side for assuring that all weeds are cut.

Figure 7: Tine configuration of the multi-purpose toolbar to show overlap. (Source: Sims, 1987)



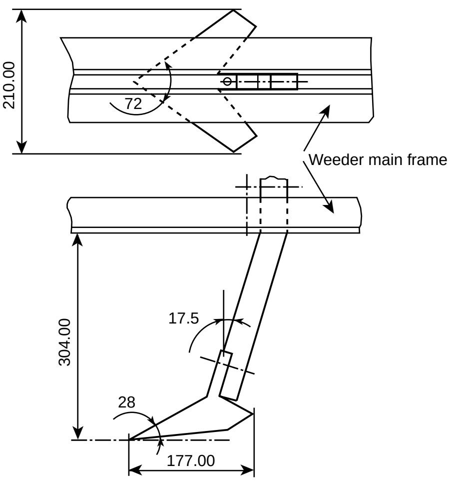


Figure 8. Specifications of the tines and supports of the multi-purpose toolbar. (Source: Sims, 1987)

The tine support bracket, while not being curved in the form of a 'C', does have a rearward inclination of 17.5° and this can be expected to reduce the build-up of cut weeds over the soil failure area. The clearance of 304 mm between the tine tip and the weeder main frame is conducive to good trash clearance.

Alternative designs

Although narrow and 'A' tines are the most frequently encountered soil acting components of animal draft weeders, other designs are also used. Ard-type plows, introduced from Spain by the *conquistadors*, are commonly used by smallholder farmers in many parts of Latin America (Figure 9).

Mouldboard plows and ridgers are also used and the latter may be used in combination with narrow-tined cultivators (Figure 10).

The complex nature of soil failure, soil inversion and weed coverage with these implements can be analysed with reference to the narrow tine model for ard and ridger points and mouldboard design for the inversion process. Mouldboard design is a wide topic and a detailed discussion is beyond the scope of this paper. However, some general points can be made.

The severity of soil manipulation will depend on the curvature of the mouldboard (the greater the degree of concavity the more the soil prism will be disintegrated during the inversion process). The angles of attack ( ) and approach (β) of the share also influence the treatment received by the prism as indicated in Figures 11 and 12).

Figure 9: Ard plow used for primary tillage and weed control

Evaluation criteria

The evaluation of equipment for small farmers should include several components. Initially a proposed innovation should be appraised from an economic and social viewpoint. If the technology does not fulfil a need felt by the farm family, or if it cannot be justified financially, further evaluation may be sterile. However, if further development of the technology can be justified, then a technical evaluation will give information on the performance and ease of operation.

Before any evaluation procedure is applied, there should be a clear idea of the potential use of the information that will be produced. Slavishly following published procedures, such as those of the Regional Network for Agricultural Machinery (RNAM, 1983), is not recommended as much information may be generated which may be marginal or irrelevant to the actual requirement. Rather, those elements of a procedure should be selected which will yield data which are directly useful for a given situation.

Figure 10: A Mexican animal-drawn cultivator with a combination of narrow tines and a ridging body for weed control and earthing up

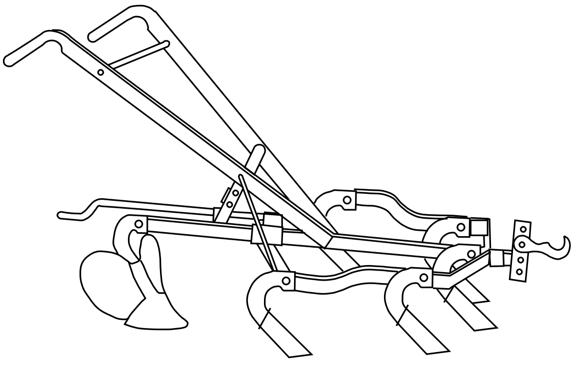
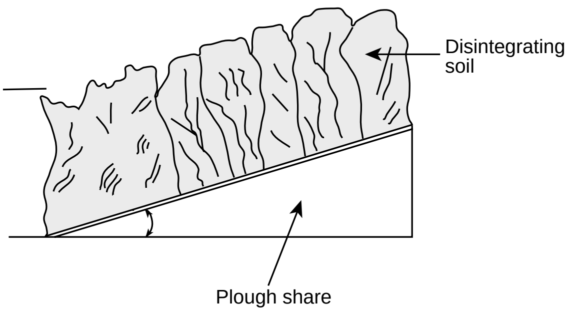


Figure 11: Attack angle (α) of a mouldboard plow share. The share initiates the process of lifting the soil prism and so an increase in α will increase prism disintegration. (Source: Ashburner and Sims, 1984)



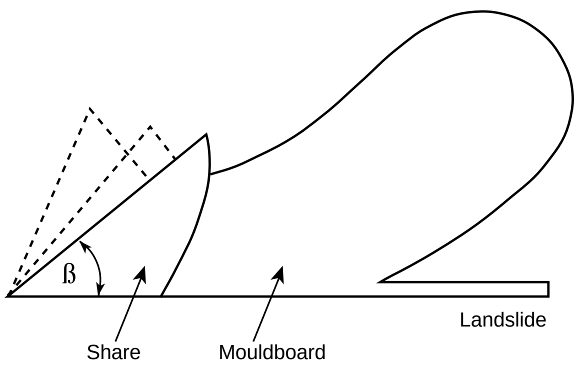


Figure 12: The approach angle (ß) of a plow share will affect plow penetration in hard soil in the way described for 'A' shaped weeder shares (see Fig 3) (Source: Ashburner and Sims, 1984)

Technical parameters

Soil type and condition

For the technical evaluation of any implement with soil acting components, the characteristics of the soil at the time of the test are of importance to enable performance to be compared under different conditions.

The principal characteristics to be considered are: particle size distribution or texture; moisture content; bulk density; size of clods; cone resistance and shear strength. Methods which require a minimum of specialised equipment are preferable, and the procedures described in a practical training course developed by Silsoe Research Institute (Smith and Sims, 1992) are offered as a starting point.

Crop and weed effects

If weed control is to be carried out in a growing crop, the crop characteristics of variety, age after emergence, height, population and spacing should be recorded. The varieties of weeds, their height and populations, must also be defined.

Besides observation, weeding efficiency is quantitatively expressed as the ratio of numbers of weeds present after the operation to that before it.

$$F = \frac{W_P - W_E}{W_P} \times 100$$

where

F = indicator of weeding efficiency

W_P = number of weeds per unit area before the operation

W_E = number of weeds rooted after the operation

This can be done most conveniently using a square frame made of wood and angle iron, with inside dimensions of 1 m each side. The frame is dropped on the unweeded land and the number of weeds of each variety in the 1 m square are recorded. In an evaluation plot measuring 40 x 10 m at least five readings should be taken.

After weeding, a similar count is taken to record the number of undisturbed weeds in the 1 m square frame. This is not a strictly accurate measurement if done immediately after weeding as weeds only slightly disturbed or lightly covered may continue to grow. It is preferable to return to the plots some two to three days after the operation to measure the populations of living plants.

Crop damage

Both the draft animals and the implement may cause damage to the crop during weeding. Damage can be assessed by counting crop plant populations before and after passage of the animal/implement combination.

Working width and depth

Working width may be measured by a graduated rule or tape. Working depth can conveniently be calculated by measuring the distance between a mark on the frame and some of the tine points. During work, the distance from the same marks to the soil surface is measured and the difference between the two measurements is the depth of work.

Implement draft, forward speed and power

The draft force exerted by the implement is measured by installing a dynamometer between the implement hitch and the animal towing chain or rope.

If the line of draft is not horizontal, measurements should be made of the hitch arrangements and angle of pull. The horizontal component of draft force can be calculated as shown in Figure 13.

Working speed is calculated from the time taken to weed a distance of 20 m. Power is calculated from the draft force and forward speed as follows:

Power (kW) = draft force (N/1000) x speed (m/s)

Work time, field capacity and field efficiency

Total work time is the time measured between the start of the first weeding run and the end of the last. It includes time taken for turning at the headlands, for rests and for any breakdowns or adjustments.

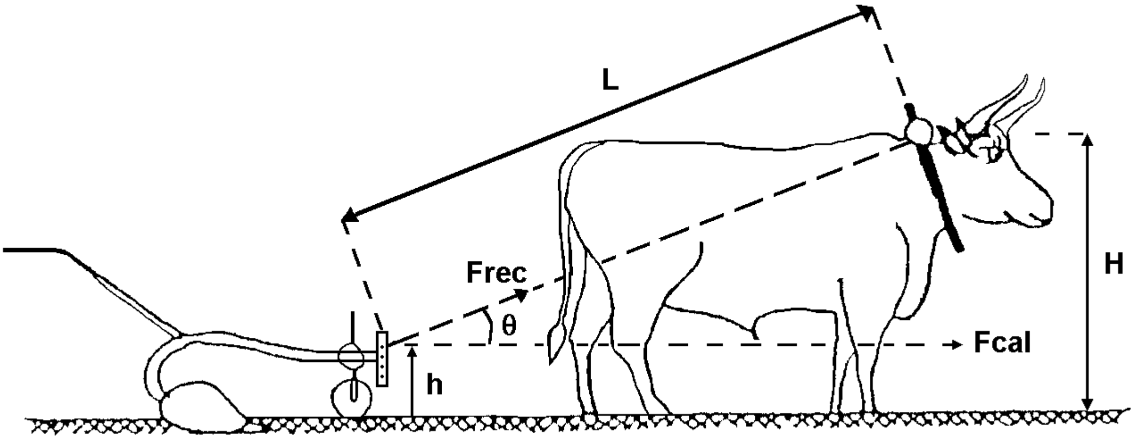


Figure 13: Line of draft and the horizontal component of draft force. The horizontal component can be calculated as follows: $F \quad calculated \quad \dfrac{F \; recorded \quad \sqrt{[L^2 \quad (H \quad h)^2]}}{L}$

or: $F \quad calculated \quad F \; recorded \quad \cos$

(Source: Zambia, undated)

Effective field capacity ($FC_{E)}$ is the average output per hour, calculated from the total area weeded in hectares and the total work time.

Theoretical field capacity (FC_T) is calculated from the *mean* values of working width and working speed, as follows:

$$FC_T \quad working\ width \quad mean\ speed$$

Field efficiency (FE) gives an indication of the time lost in the field and the failure to use the full working width of the implement. It is calculated as follows:

$$FE\ (\%) \quad \frac{FC_E}{FC_T} \quad 100$$

Durability

In order to obtain more accurate measurements of wear of working parts, and to highlight any possible problems of maintenance and operation, trials may be made covering longer periods of work (about 100 hours).

Trials on farmers' fields should be undertaken to enable the implement to be evaluated in varied field and soil conditions: users' comments should be invited.

All details of plot conditions and measurements specified in the performance tests should be recorded throughout these trials, together with comments on operating characteristics.

Ergonomic appraisal

A full ergonomic evaluation of the operation of an animal-drawn weeder may be required for specific research or development purposes. Usually, however, as animals rather than humans are being used as the power source, a subjective assessment will fulfil the requirement. Ergonomic aspects of weeder operation assessment will include:

Ease and comfort of operation

The machine should be operated for at least four hours by a range of operators who reflect the likely population of users. This may include men, women and children, and will certainly include a range of body sizes and weights within each category. To select the sample of operators, anthropomorphic (body dimensions) data of the user population must be available.

Subjective appraisal of the comfort of operation and the force required for control can be augmented using a 'body map' (Figure 14). The body is divided into sections and the operator can indicate which sections are sites of pain or discomfort as a result of the task. A rating scale (eg, 0 to 5, for no discomfort to severe discomfort) will facilitate comparisons between user types and different weeders.

The ease of control and manoeuvrability of weeders, especially inter-row weeders, is critical to minimise crop damage. Evaluation with a range of users will determine whether the weeder is operated as intended and the facility with which it can be controlled.

Ease of adjustment and cleaning

The operators will effect the available adjustments on the weeder (eg, width of work,

This paper is published in: Starkey P and Simalenga T (eds), 2000. *Animal power for weed control.* A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA). Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, The Netherlands. ISBN 92-9081-136-6. For details of ATNESA and its resource publications see **http://www.atnesa.org**

hitch point adjustment, number and type of tines) and will comment on this and the ease of clearing accumulated trash.

Safety

Any aspects of the design, materials, finish or operating requirements that may constitute a possible danger to any operator group (or the animals) will be reported.

Economic appraisal

An economic appraisal is necessary under various circumstances: before embarking on the development of new equipment: when new equipment has been developed; or if contemplating a change of system, for example replacement of human power for animal power for the weeding operation. This section summarises the basic concepts required (Williams and Sims, 1993).

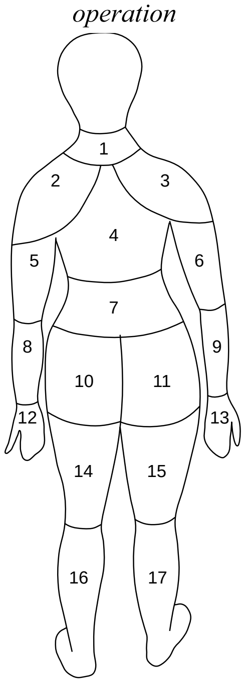
Calculation of costs and benefits

A producer who invests in farm machinery is confronted by three basic costs:

- cost of capital associated with the purchase
- costs of operation and maintenance of the equipment
- cost of replacing the equipment at the end of its useful life.

Costs can be divided into two groups: fixed and variable. As an example, consider the purchase of an animal-drawn weeder which will be used for 100 hours per year over a period of eight years before it will need to be replaced: an analysis of the costs is given in Table 1.

Figure 14: Body map used for evaluating comfort of operation



Fixed costs

In general the fixed costs are independent of the amount of work that a machine does per year. The most important components are depreciation and interest paid for the use of the invested capital.

Depreciation is calculated by dividing the purchase or new value of the machine (VN) by the estimated number of years of useful life (UL). If it is expected that the machine will be sold at the end of its period of use, a residual value (VR) is estimated. In this case the depreciation is calculated by dividing the average value by the useful life:

(VN-VR)/UL

In high inflation situations it is advisable to review the value each year and use a realistic market value of VN.

For interest calculations it is assumed that the farmer uses money lent by a bank and the interest rate (i) is the current market rate (14% in Table 1). If the farmer uses his/her own money, an opportunity cost is applied. This will be the interest rate which could be achieved in the best alternative use of the invested capital. As a minimum opportunity cost, the current market rate is applied.

Once the interest rate has been determined, the annual interest cost is calculated a follows:

(VN+VR)/2 x i

The new and residual values are summed, as together they represent capital that cannot be invested in other ways. The total investment is divided by 2 to calculate the annual interest charge over the useful life.

Variable costs

Variable costs vary with the amount of use that the machine receives. They comprise the costs of replacement parts, maintenance and repair, and operators' time.

The best way to estimate these costs is to maintain a register of those previously incurred in the use of similar equipment. If, as is often the case, such information does not exist, the costs can be estimated using manufacturers' recommendations or published guidelines. For example, Hunt (1973) suggests a value for repair and maintenance for cultivation equipment of 6% of the purchase or new value (VN) per 100 hours of use.

Table 1: Example calculation of annual fixed and variable costs of farm machinery (animal-drawn weeder)

New value	$2000
Residual value	$500
Useful life	8 years
Annual use	100 hours
Annual interest rate	14%
Annual fixed costs	**$**
Depreciation (VN-VR)/UL	187.50
Interest (VN+VR)/2 x i	175.00
Subtotal	**362.50**
Annual variable costs	**$**
Replace 1 tine @ $50	50.00
Labour, welding material etc	40.00
Subtotal	**90.00**
Hourly fixed and variable costs	**$**
Fixed costs/h (362.50/100h)	3.62
Variable costs/h (90.00/100h)	0.90
Total fixed and variable costs per hour	**4.52**

1) The $ sign represents financial costs but does not idicate any specific currency

Economic performance of machinery

In order to use information on machinery costs for budget analysis, it is necessary to express them in terms of work done. This requires output to be calculated (in, for example, ha/h, kg/h, etc).

The test procedure described in above details methods that enable output to be calculated by means of controlled tests under realistic conditions.

As an illustration, the performance of an animal draft weeding operation can be analysed assuming the use of the weeder analysed in Table 1. The performance characteristics are shown in Table 2. A similar calculation for the costs of owning draft animals is shown in Table 3.

Partial budgets

Although the calculation of machinery operation costs is made possible through field evaluation, the effect on a farming system of small changes, such as the adoption of alternative mechanisation technologies, requires budget analysis.

Whole farm budgets quantify the profitability of the farming system and its components and are needed when large-scale system changes are contemplated. Smaller changes (such as changes of crop variety, area sown or machinery employed) can be assessed by the use of the simpler partial budget (see Table 4).

Partial budgets only include those variables which vary with the proposed change. For example, a change in weeding method would not (necessarily) imply a change in type or volume of fertiliser applied, so the cost of fertiliser would not be included in the budget. The simplest and most useful form of partial budget is that which analyses the net benefit of a proposed change.

The first step in partial budget formulation is to describe in detail the proposed change and to note the date of budget preparation. The budget comprises four elements:

Costs	**Benefits**
additional costs	costs avoided
income forgone	additional income

Table 2: Example calculation of output and cost of weeding with an animal-drawn weeder

Cost of labour	$12/day[1]
Working day	6 hours
Total equipment cost (fixed and variable)	$4.52 x 6 = $27.12/day
Total animal cost[2]	$6.60/day

Operation	Width (cm)	Speed (m/s)	Field efficiency (%)	Ouput (ha/h)	Output (days/ha)	Total cost ($/ha)
Weeding	50	0.80	75	0.11	1.52	69.49

1) The $ sign represents financial costs but does not idicate any specific currency
2) Calculation of draft animal costs is explained in Table 3

This paper is published in: Starkey P and Simalenga T (eds), 2000. *Animal power for weed control.* A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA). Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, The Netherlands. ISBN 92-9081-136-6. For details of ATNESA and its resource publications see **http://www.atnesa.org**

This paper is published in: Starkey P and Simalenga T (eds), 2000. *Animal power for weed control*. A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA). Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, The Netherlands. ISBN 92-9081-136-6. For details of ATNESA and its resource publications see **http://www.atnesa.org**

The impact of the proposed change on net benefit is calculated by subtracting the total new costs from the total new benefits. If the benefits are greater than the costs, then the change is advantageous; if not, then it would not be recommended.

It may be that some of the factors that may influence the decision on whether or not to change may not be easy to quantify and include in the budget. In this case a list of the non-monetary factors is included as a footnote. Examples include: the degree of risk associated with the proposed change; changes in family labour requirements; need for credit, etc.

As an example, consider a farmer who grows two hectares of vegetables for sale. Hitherto the farmer has hired manual labour, but now that this is in short supply at peak periods of demand, he/she suspects that it may be more profitable to hire a neighbour's oxen and weeder. The farmer realises that yields may suffer as a result of the system change, but still considers that it may be advantageous.

Table 4 shows the partial budget for the proposed change. It defines the proposal and then details the costs and benefits generated and the net benefit expected. Non-monetary considerations are also noted.

Proposed change and other considerations

Replace hired labour for weeding two hectares of vegetables twice per season with a hired draft oxen–weeder combination.

The proposed change will reduce the time per weeding from 15 days to 6 days and this may have a positive effect on yields.

Table 3: Example calculation of draft animal costs

New value of oxen	$6000
Residual value of oxen	$6000
Useful life	5 years
Annual use	850 hours
Annual interest rate	14%
Price of fodder	$0.9/kg
Hourly labour cost per person	$1.50
Yoke	$50.00
Annual fixed costs	**$**
Depreciation (VN-VR)/UL	0.00
Interest (VN+VR)/2 x i	420.00
Subtotal	**420.00**
Annual variable costs	**$**
Supplementary feed @ 100 kg/animal	180.00
Yoke: 1 per 3 years	16.67
Straps and ropes @ 0.01 VN/year	60.40
Veterinary costs @ 0.02 VN/year	120.00
Care @ $1.75 hours/week	136.50
Subtotal	**513.17**
Total annual costs	933.17
Total hourly costs	**1.10**

Note: The $ sign represents financial costs but does not idicate any specific currency

Table 4: Example partial buget for the change of weeding technology for vegetables

Costs		**Benefits**	
Additional costs	**$**	**Costs avoided**	**$**
Hire of oxen and weeder @ $60/day 1.52 days/ha x 2 ha x 2 weedings =	365	Hired labour @ $12/day 15 person days x 2 ha x 2 weedings	720
Farmer's labour: 6 days @ $12/day	72		
Sub total	**437**	**Sub total**	**720**
Income forgone		**Additional income**	
Vegetable yields with hand weeding	2200	Vegetable sales with ox weeding	2000
Total cost	**2637**	**Total benefit**	**2720**

Net benefit = Total benefit - total costs = **$83**

Net benefit/ha = **$41.5**

Note: The $ sign represents financial costs but does not idicate any specific currency

Acknowledgements

The developmental work in Mexico and the production of the Silsoe Research Institute farm machinery testing course notes have been done within projects funded by the British Department for International Development (DFID), previously known as the Overseas Development Administration (ODA). The help of DFID/ODA is gratefully acknowledged.

References

Ashburner J E and Sims B G, 1984. *Elementos de diseño del tractor y herramientas de labranza.* Instituto Interamericano de Cooperación para la Agricultura, San José, Costa Rica. 12p.

Chase L W, 1942. A study of subsurface tiller blades. *Agricultural Engineering* 23:43–45, 50.

Hunt D, 1973. *Farm power and machinery management. Laboratory manual and workbook.* Iowa State University Press, Ames, Iowa. 292p.

RNAM, 1983. *RNAM test codes and procedures for farm machinery*. United Nations Development Program, Economic and Social Commission for Asia and the Pacific. Regional Network for Agricultural Machinery, Pasay City, Philippines. pp. 131–149.

Payne P C J and Tanner D W, 1959. The relationship between rake angle and the performance of simple cultivation implements. *Journal of Agricultural Engineering Research* 4(4):313–328.

Sims B G, 1987. *Mecanización para el pequeño agricultor. Secretaría de Agricultura y Recursos Hidráulicos* (SARH), Instituto Nacional de Investigaciones Forestales y Agropecuarias, Campo Cotaxtla, Veracruz, Mexico. 384p.

Sims B G, Moreno Rico D and Albarrán Simón J, 1987. Control de maleza con cultivadoras de tracción animal para el pequeño productor. *Agric. Téc. Méx.* 13(1):41–60.

Smith D W and Sims B G, 1992. *Technical evaluation of small farm equipment.* Presented at the Eleventh Session of the FAO Panel of Experts on Agricultural Engineering, 28–30 October. FAO (Food and Agriculture Organization of the United Nations), Rome, Italy. 233p.

Spoor G, 1969. Design of soil engaging implements. Parts I and II. *Farm Machinery Design Engineering* 3:22–25, 28.

Tanner D W, 1960. Further work on the relationship between rake angle and the performance of simple cultivation implements. *Journal of Agricultural Engineering Research* 5(3):307–315.

Tewari V K, Datta R K and Murthy A S R, 1993. Field performance of weeding blades of a manually operated push-pull weeder. *Journal of Agricultural Engineering Research* 55(2):129–141.

Williams G R and Sims B G, 1993. *Elementos de economía agrícola. Manual para investigadores y técnicos de campo con enfasis en la mecanización agrícola.* Centro Universitario Pinar del Río. Pinar del Río, Cuba. 34p.

Zambia, undated. Test procedures for animal drawn mouldboard ploughs. *Draft Zambian Standard* No 210. Animal Power Research and Development Project and Farm Machinery Research Unit, Magoye, Zambia. 50p. and annexes.

This paper is published in: Starkey P and Simalenga T (eds), 2000. *Animal power for weed control.* A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA). Technical Centre for Agricultural and Rural Cooperation (CTA), Wageningen, The Netherlands. ISBN 92-9081-136-6. For details of ATNESA and its resource publications see **http://www.atnesa.org**