Animal-powered weeders in Africa: interactions between design, manufacture and operation

by

F M Inns

Leverhulme Emeritus Fellow, 53 Alameda Road, Ampthill, Bedford MK45 2LA, UK

Abstract

The design of animal-powered implements has proceeded on an empirical basis for thousands of years. A theory dealing with working relationships between animal and implement endorses the design of many traditional implements and provides guidelines for the accelerated development of new ones. Its application to the design of weeding implements is discussed. Design must also take account of the agricultural and industrial systems within which the implements are manufactured and operated; some relevant influences are considered.

Status of animal-powered weeding in sub-Saharan Africa

In much of Africa south of the Sahara the use of animal power is still not widespread. Its use follows the historical pattern detected by Binswanger (1988); the first applications have been for power-intensive operations such as cultivating with a plow, ridger or scarifier, and transport using a cart or sled.

Although weeding is less power- consuming than cultivation operations it is labour-intensive and its execution requires more judgement. Fast weed growth and consequential large reductions in crop yield make timeliness of weeding critical; the operation should therefore be under the direct control of the farmer. This combination of factors indicates that weeding is a candidate for early mechanisation using farmer-controlled animal power.

Animal-draft weeding in context

The implement used for animal-powered weeding is at the heart of a series of complex systems influencing its effective employment, as shown in Figure 1. The implement interacts directly with the draft animal, the soil, crops, weeds and the farmer/operator. These components and their interactions may be considered as constituting the core system. It has many external interactions with the agricultural production system and, beyond that, with comprehensive national and international arrangements.

It is necessary to pick out some factors and interactions judged to have a major influence on the design of an implement intended for use in the animal-powered weeding system. The following essential interactions will be considered:

- influence of the crop production system
- interactions within the animal-draft weeding system
- manufacture and upkeep of the weeding implement.

Influence of crop production systems

Crops must be planted in rows to take advantage of animal-draft weeding. Many crops, such as maize, groundnuts, cotton, etc, are commonly planted in rows at spacings of 60–90 cm, which are convenient for animal-draft weeding; other crops which traditionally may be broadcast (sorghum, millet) could be row planted at similar spacing.

Most seed is hand planted by farmers. Hand planting is often as quick, or quicker, than using a machine, but rows planted by hand may not be straight and parallel.

Row spacing may be varied deliberately. In Niger, for example, the spacing of sorghum is varied to take account of topography and the soil moisture likely to be available during the growing season, based on the farmer's knowledge of local conditions. In one survey, Ohler (1987) found that the average row spacing between lines of plants (sorghum and millet) varied from about 90 to 125 cm, and that the spacing varied along the rows by up to about 15% of the average value. These crops had not been planted with animal-powered weeding in mind; probably the variation could have been reduced, even when planting by eye, if this had been considered necessary.

It is not reasonable to expect farmers to plant in the straight parallel rows typical of experimental stations; therefore the implement or method of working should tolerate discrepancies of the order mentioned above. Additionally, because growing on ridges is practised widely, the implement should be adaptable to deal with this until such time as acceptable methods for growing on the flat may become popular.

Design and operation of a tined weeder

It should be possible to cover the necessary inter-row working width with a three-tine cultivator (five optional), assuming that the tines may be fitted with a variety of points, including chisel points, duckfoot points and weeding sweeps. Depending on local farming practices it may be necessary to provide for the outer tines to be adjustable vertically relative to the implement's frame, to conform to the ground topography between ridges. Small mouldboards might be fitted to outer tines, throwing soil towards the crop lines to maintain the ridges.

Many five-tine cultivators are of the expanding type, with the width of work adjustable by a single lever. These cultivators, typically copied from traditional European models, are heavy and unduly complicated. A fixed triangular frame or backbone frame will be more robust for a given weight. Any variations of inter-row width due to hand planting can be dealt with by travelling twice down each inter-row gap.

Interactions in the weeding system

Stability in work

When correctly adjusted for straight-line work, an animal-draft weeding implement should ideally run in a stable condition, without undue interference by the operator. The operator's efforts should be limited to making minor corrections necessitated by normal variations in working conditions, to guiding the implement (predictably and accurately, with minimum application of force) and to turning at the headlands.

Animal–implement relationships

Force interactions between tractors and soil-engaging implements have been extensively studied and documented. The importance of angle of pull is well known and taken into account in tractor and implement design to ensure optimum system performance (Inns, 1985). The importance of angle of pull in

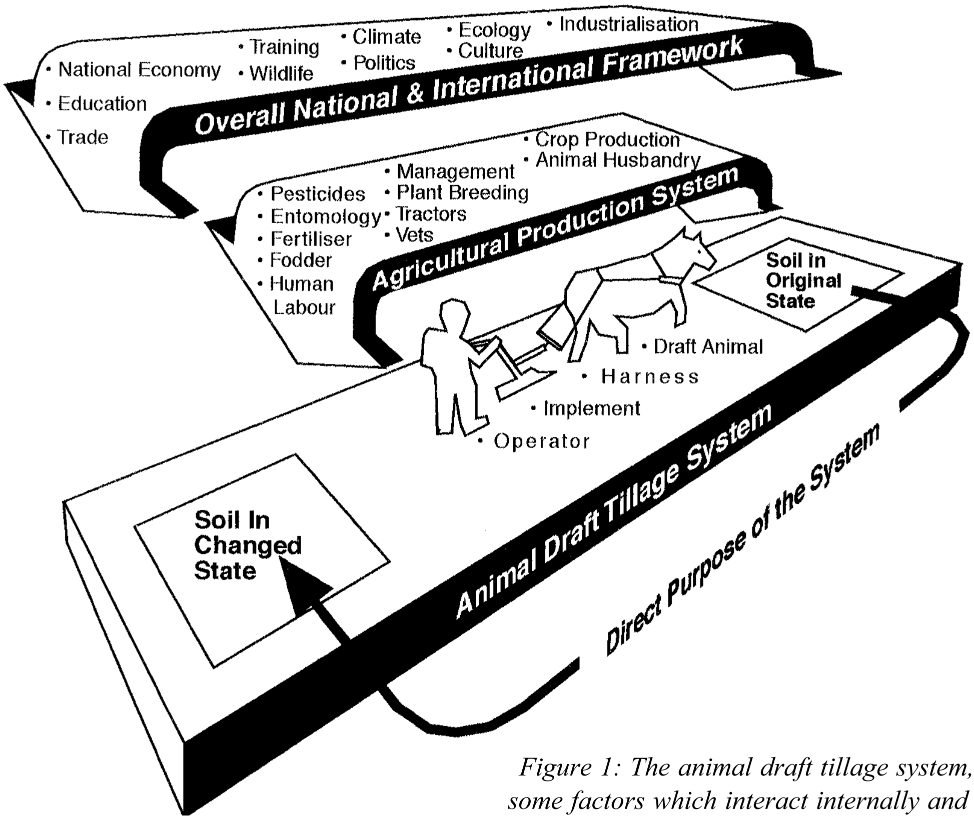

Figure 1: The animal draft tillage system, showing some factors which interact internally and externally

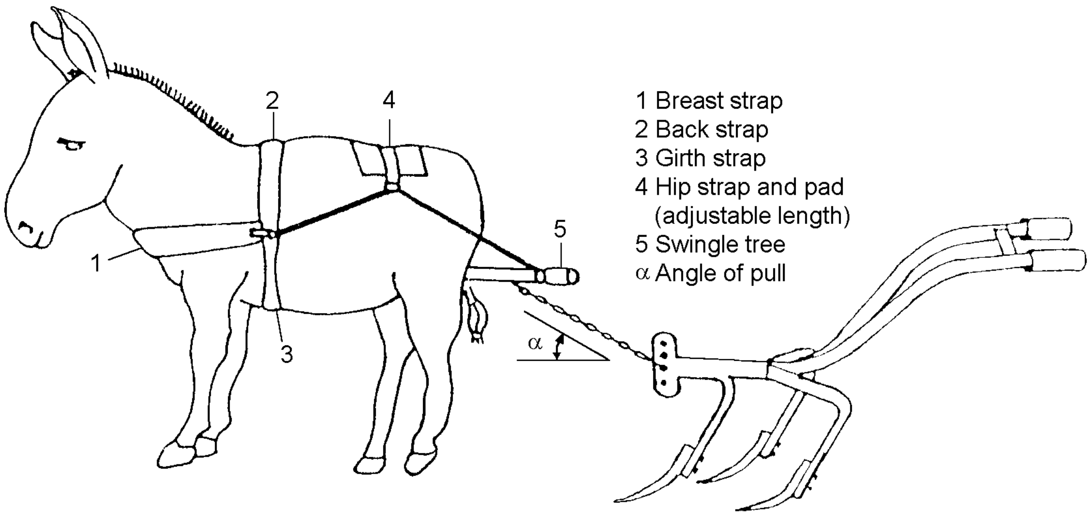

Figure 2: Proposed arrangement for a single-donkey harness providing an adjustable angle of pull

the design of animal-drawn implement systems is less well known but is probably more critical than for tractors, because the pull demanded from draft animals must be kept to levels that they can sustain through a working day.

It has been shown (Inns, 1990, 1991) that the equilibrium draft of a soil-engaging implement is a function of its weight, the angle of the pulling force applied to it by the animal, the soil forces acting on it, and possible intervention forces (which should be small) from the operator. The angle of pull is affected by the size of the draft animal (it is steeper for taller animals), and the type and design of harness. It is usually possible to vary the angle of pull within fairly narrow limits with existing harnesses; alternative designs which permit an extended range of adjustment are not difficult to devise (see, for example, Figure 2 in which the hip strap is adjustable in length).

Implement weight

The relationships between implement draft, effective vertical force acting on the implement and angle of pull are summarised in Figure 4. Because the vertical (downward) soil force acting on a weeding tine is likely to be quite small, the effective vertical force will consist mainly of the implement weight. Assuming a single working animal, the maximum draft for a continuous working day is about 200 N for a single donkey (Betker, 1991) and about 300 N for a 300 kg ox. With a 15° pull angle these draft values correspond to implements weighing about 50 N (5 kgf) and 75 N (7.5 kgf), respectively. For a 30° pull angle (which could be provided by a suitable harness design) the corresponding values are about 100 N (10 kgf) and 150 N (15 kgf), respectively.

These target values for implement weight are much lower than is feasible for an implement made of steel. The implement should therefore be made as light as possible consistent with the strength required to deal with normal operating forces, using a factor of safety appropriate to the detailed structural design of the implement.

Ensuring implement penetration

The theoretical relationships referred to above assume that the implement is not supported by soil forces when in work, ie, that shares and points are sharp and set to work with adequate clearance angle behind the point. In practice, points will become rounded by wear, generating support forces from the soil that counteract the implement's weight, and consequently reducing the effective vertical force and the equilibrium implement draft and depth of work. The effect of worn points is to cause what is normally called 'lack of penetration'. This condition should more properly be called 'excessive soil support', thus drawing attention to the fundamental remedy for this condition, namely, to sharpen the points and ensure that they are correctly set to give a good clearance angle behind them, so eliminating excessive support or reducing it to an acceptable level.

The soil support force generated by worn shares will vary with the degree of wear and the exact geometry of the worn components. This effect has not been quantified: it would be a good topic for research. Overall the effect will be that the implement is increasingly reluctant to reach its full equilibrium depth,

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although the depth actually achieved may well be acceptable—the potential full working depth may be deeper than is desirable.

Control of working depth

It is necessary to control working depth to ensure optimum agronomic effect (depth of operation of weed-cutting sweeps) or to avoid excessive draft. Wheels or skids are widely used for this purpose; they act by generating a support force from the soil which reduces the effective vertical force acting on the implement and hence also the implement draft and depth. Wheels or skids are undoubtedly effective, but they increase implement cost and, by adding weight to the implement, exacerbate the problem they are intended to solve. The more fundamental and elegant approach is to reduce implement weight and apply the pulling force at a steeper angle. The extent to which these actions can be pursued is limited by harness and implement design; it may still be necessary to use a simple skid to provide a small residual support force. In such cases the skid should be located close to the centre of gravity of the implement, where it will have least effect in upsetting the balance of forces acting on it.

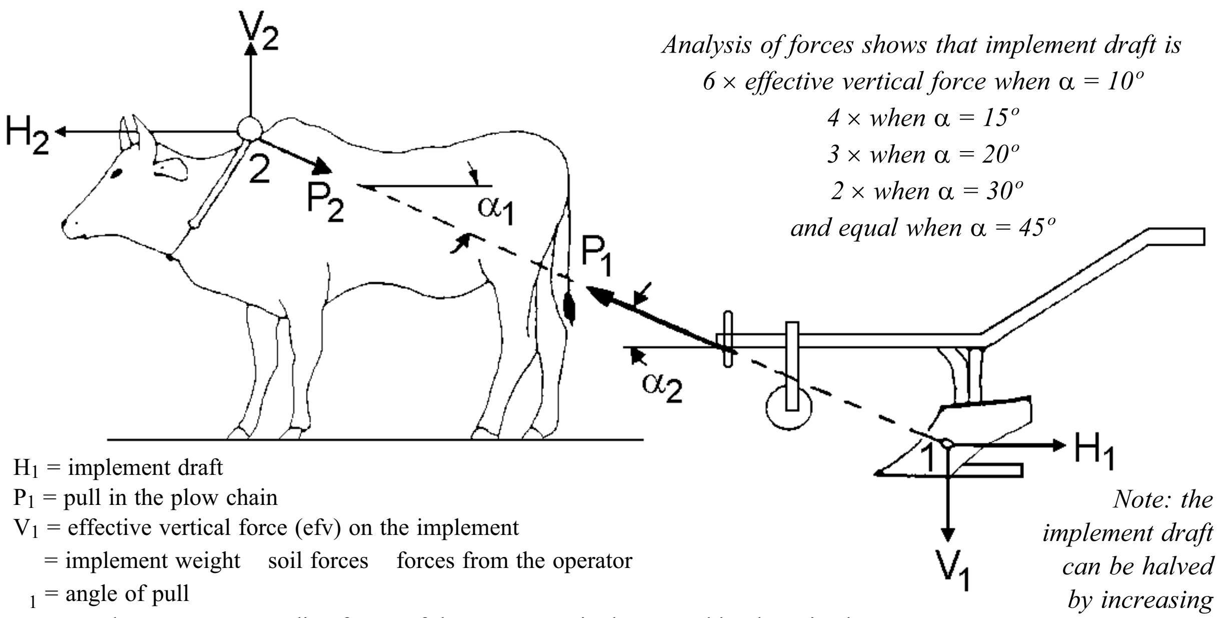
Chain-pulled or beam-pulled implements

Chain-pulled implements dominate the scene in sub-Saharan Africa, probably because they were used widely in Europe at the time of their introduction to Africa. Traditional beam-pulled implements continue to demonstrate their effectiveness in North Africa, the Middle East and Asia. The relative merits of each type are finely balanced. Well-designed beam-pulled implements are generally lighter and easier to control, but are not so well suited to single-animal operation. The principles underlying their design are fundamentally the same as those for a chain-pulled implement, but their mode of application in practice is somewhat different. It is the author's opinion that their potential for use with two-animal teams in sub-Saharan Africa is high and is worthy of comprehensive investigation.

Harness design

The harness provides the essential link between animal and implement, governing the forces acting on each. Empirical development has resulted in effective designs but it is necessary to know *why* they are effective if future developments are to be guided productively. Empirical evidence suggests that the useful effects of a steep angle of pull are already appreciated and incorporated into some existing designs: sometimes fortuitously in the case of harnesses for camel-pulled implements; sometimes more deliberately in the case of saddle-harnesses which are used with horses and mules in Latin America. The design illustrated in principle in Figure 2 is consistent with these existing practices, and is backed by the theoretical analysis shown in Figure 3. An

Figure 3: Forces between the animal and a chain-pulled plow (Source: Inns, 1990)



H_1 = implement draft
P_1 = pull in the plow chain
V_1 = effective vertical force (efv) on the implement
= implement weight soil forces forces from the operator
$_1$ = angle of pull
$_2$, P_2 and V_2 are corresponding forces of the same magnitude, exerted by the animals.
Angle $_1$ has the same magnitude as angle $_2$

Note: the implement draft can be halved by increasing the angle of pull from 15° to 30°

example of this harness is shown in Photo 1. When traditional practice and theory reinforce each other the opportunities for soundly-based accelerated development must be enhanced.

Manufacture and upkeep of animal-powered implements

The farmer's demand for agricultural machines (hand tools, implements and more complex machines) has traditionally been met initially by local manufacturers in collaboration with innovative and inventive farmers. In more industrialised countries innovations have been taken up and developed for large-scale manufacture and marketing.

The farmer–manufacturer relationship remains strong in many countries; in others it may be undermined by well-meaning but inappropriate (or poorly executed) government interventions. Thus in Pakistan there is a thriving industry in the production of animal-powered implements by local artisans, despite (or because of?) the policy pursued by government-supported research institutions to concentrate efforts on tractor-powered mechanisation to the exclusion of animal-powered developments. In contrast, in Nigeria the local production of hand hoes is in precarious balance despite a strong tradition of local production. Government policies to encourage local production of animal-powered implements are stalled, despite the willingness and ingenuity of local artisans.

The author's involvement with these two situations leads to the conclusion that the essential difference that is determining success and failure lies in the industrial infrastructure, particularly as it relates to the supply of materials, equipment and trained artisans. A range of steel stock and off-the-shelf components (nuts and bolts, tine points, bearings, etc) is widely available in the small towns and large villages of Pakistan, but not in Nigeria. The availability of tools and equipment shows similar differences. Formal artisan training is not well catered for in either country. Traditional training from master to apprentice is maintained, but considerably influenced by future prospects of profitable employment and business opportunities for trained artisans, which are generally poor in Nigeria due in large measure to the difficulties in obtaining essential raw material inputs.

The design of animal-powered implements must be seen against the background of potential

Photo: F Inns

Photo 1: Donkey fitted with the suggested harnessing system, during assessment trials in UK

production arrangements. Demand-led production by local artisans, properly supplied and equipped and working in close collaboration with their customers, is at one end of the spectrum: large-scale manufacture is at the other. Both arrangements are potentially effective, but designers must ask themselves which is the most realistic option in their own circumstances and direct their efforts accordingly.

Acknowledgement

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