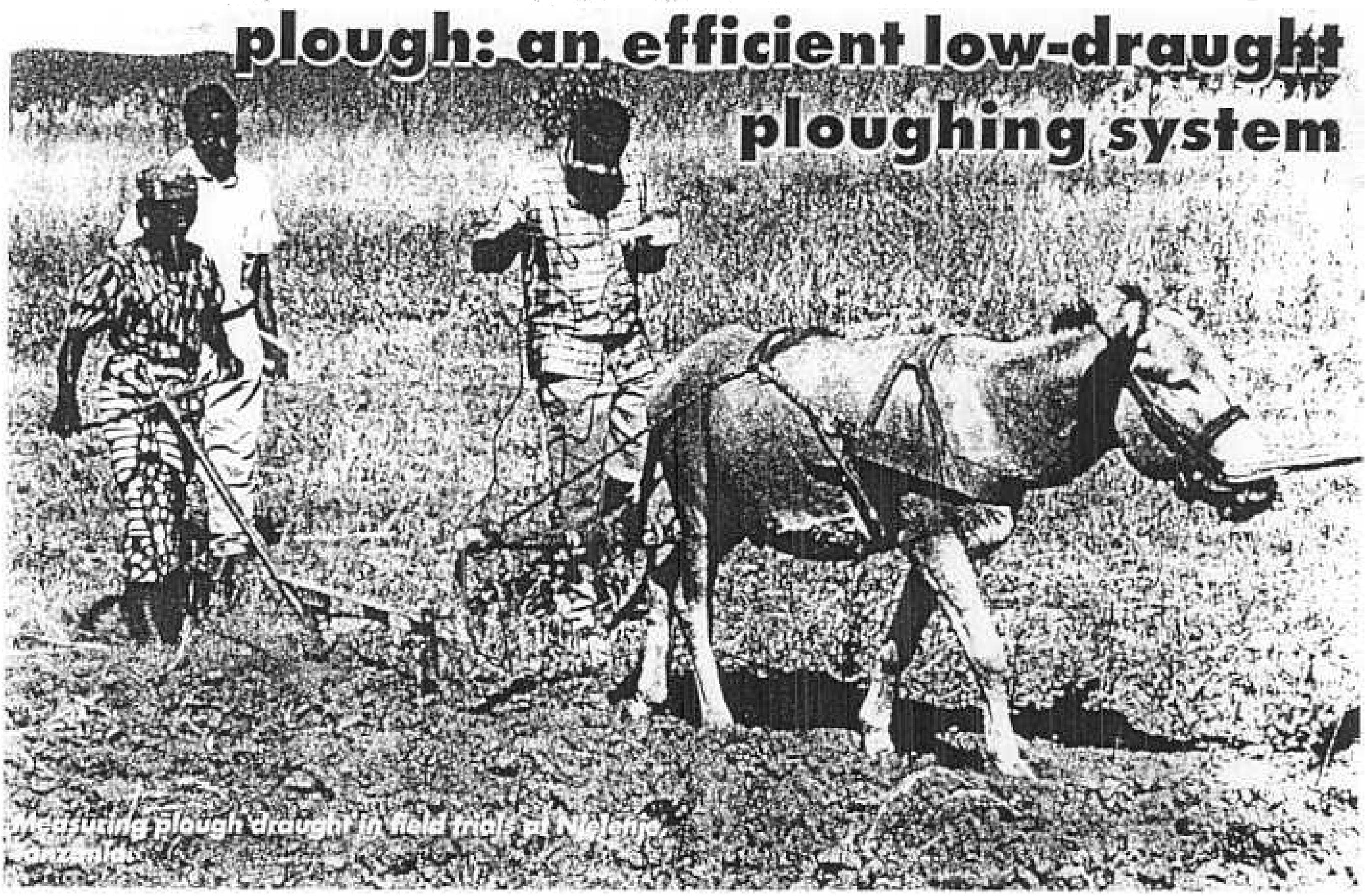
High-lift harness and lightweight plough: an efficient low-draught ploughing system



Measuring plough draught in field trials at Njelenje, Tanzania.

Frank M Inns

1. Development of a high-lift harness and lightweight plough system

Background to the 'high-lift' system

Draught animal cultivation systems have been the subject of much research for several thousand years. Until recently, it has been conducted by farmers on a trial and error basis, resulting in some remarkably efficient harness/implement combinations. More recent investigations have concentrated on implement design without considering the interaction between animal and implement, in contrast to the detailed investigations which have been made into the hitching of tractor-pulled implements.

Mouat and Coleman (1954) showed that the draught, *H*, of a cultivation implement is a function of the vertical force, *V*, acting on it and the angle, α, at which it is being pulled. The relationship may be stated in the form of a Tillage Implement Draught Equation (TIDE) as:

$$H = V/\tan \alpha$$

or, in words:

The draught of a cultivation implement varies directly with the effective vertical force (e.v.f.) acting on it and inversely with the tangent of the angle at which it is being pulled.

Although this relationship is very simple, its implications are quite profound. They have been explored in some detail by Inns (1990) with consequences which sometimes conflicted with the perceptions of designers and other experts, but were generally in accordance with the experience of users.

Experimental verification of the relationship between plough draught and angle of pull

It seemed necessary to demonstrate that the TIDE did give a true prediction of the relationship between plough draught and the angle of pull, α - consequently field experiments were conducted at the Centre for Tropical Veterinary Medicine (CTVM), Edinburgh (Inns & Krause, 1995) using a donkey and a 15 cm mouldboard plough weighing 18 kg. The predicted relationship was confirmed. It was then decided to face the challenge of designing a harness/plough system to match the draught capability of a single donkey, *i.e.* about 200 N to 250 N. This challenge is relevant to current circumstances in many developing countries in Africa and elsewhere, where there is a shortage of traditional draught animals for small-scale farming and donkeys are increasingly recognised as being an underutilised resource.

Preliminary trials were made at CTVM using a breastband harness fitted with a hipstrap to vary the angle of pull between about 20° to 35° *(as shown in*

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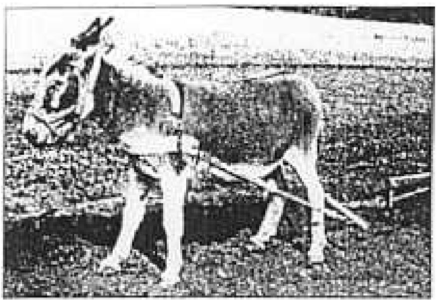


Fig. 1 Plain breastband harness - angle of pull fixed at about 20 degrees.

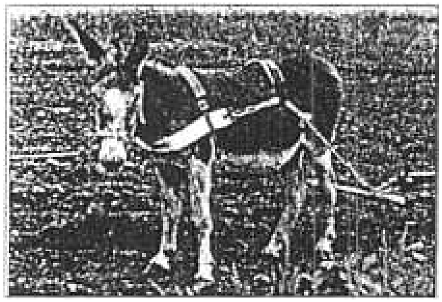


Fig. 2 Breastband harness modified by addition of an adjustable hip strap - angle of pull can be varied from about 20 to 35 degrees.

Figures 1 and 2) and a 11.5 cm plough weighing about 12 kg, which was designed to cope with the variation in pull angle. Results confirmed expectations and further trials were undertaken on-farm in conjunction with farmers in Tanzania *(see Title Photograph)*, with results as shown in *Figure 3*. In general, it appears that plough draught is halved when the angle of pull is increased from 20° to 30°, making all the difference between a no-go situation and one which the donkey can cope with throughout a working day.

Design of a high-lift harness and dedicated lightweight plough

Following from the above experiences, a simple and cheap 'high-lift' breastband type harness has been designed to provide an angle of pull of 30° approximately, as shown in *Figure 4*. The breastband harness is suitable for a single donkey, horse or mule - it is possible to design an alternative high-lift harness for oxen. By standardising the angle of pull it has been possible to design a dedicated lightweight plough weighing 8 kg and suited to manufacture in small local workshops. The harness and plough have recently (January 1998) been evaluated for use in Bolivia. Results have been excellent when working with either donkey or horse as shown in *Figures 5 and 6*. Versions of the harness and plough have been manufactured locally in Bolivia.

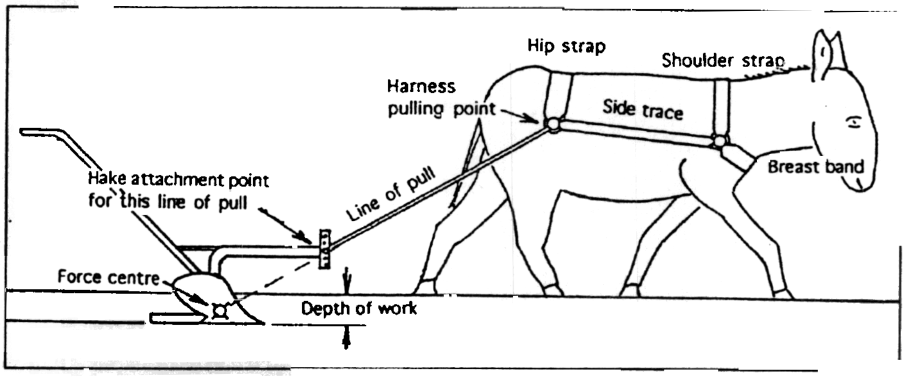


Fig. 4 Harness design: typical high-lift harness (breast band type) suitable for donkeys and other equines. This harness gives an angle of pull of about 30 degrees, or slightly more.

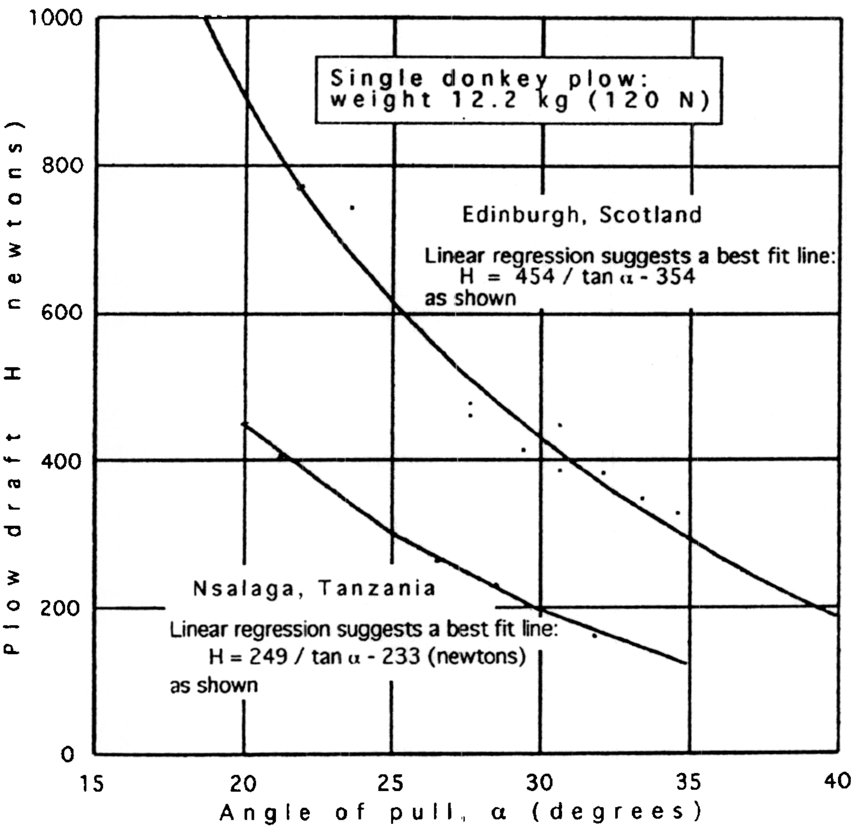


Fig. 3 Variation of draught with angle of pull: results of field trials in Scotland and Tanzania.

Advantages of the high-lift system

Advantages of the high-lift system, leading to a high degree of user-friendliness, include:

- improved plough efficiency (greater proportion of useful work);
- reduced draught load on the animals (or more useful work for the same draught level);
- easier adjustment (skids or wheels are not needed);
- simple harness (cheap, easily made locally); and
- lighter plough (cheaper, more easily transported and handled).

The improvement in plough efficiency arises from the combination of reduced plough weight and increased uplift on it as a result of the steeper angle of pull. These combine to reduce the load carried by the wheels of a wheeled plough or, in the case of a wheel-less plough, the load reduction occurs between the underside of the plough and the soil. Rolling resistance at the wheels

Fig. 5 High-lift harness and lightweight plough at work with donkey, Capinota, Bolivia.

is reduced and/or the frictional resistance underneath the plough. Plough efficiency is improved by reducing these parasitic components of draught. There are preliminary indications that share wear is also reduced.

2. Some myths and realities relating to animal powered ploughs

The investigations and design work

Fig. 6 High-lift harness and lightweight plough at work with horse, Cochabamba, Bolivia.

reported above involved considerable practical work, carefully undertaken, observed and thought about. Some light may be thrown on existing animal draught controversies as a spin-off.

The influence of plough weight on plough draught

Farmers and other practitioners of animal-powered ploughing often make statements to the effect that "this plough is too heavy for my animals (to pull)". This conflicts with a long-held belief that "the weight of the plough has comparatively little effect on its draught" (Young, 1784, quoted by Mouat & Coleman, 1954) - an opinion which is still shared by many advisers and larger scale manufacturers. What are the facts?

Older ploughs were very heavy and the e.v.f. would be very large, with correspondingly high draught, unless the plough's weight were partially counteracted by upward-acting support force(s). This was done by supporting most of the weight on a large 'sole' or 'slade' - a long horizontal plate underneath the plough - or by wheels, skids or other devices. If the support force is large enough (not necessarily easy to achieve) the e.v.f. can then be reduced to a value which will result in an acceptable level of draught - but much of it will be parasitic draught caused by friction on the sole, or rolling resistance from the wheel(s), which do no useful work on the soil.

Over the years the use of improved materials and design allowed the plough to be made lighter. The support force did not need to be so great, the sole of the plough could be made smaller, the parasitic draught was reduced and hence the plough became more efficient. It also became easier to adjust, if it had been well designed, because it was no longer necessary to provide a very large support force.

Work animals can cope with a heavy plough if it is carefully adjusted to develop a large enough support force, but unnecessary weight makes it more awkward for the ploughperson to handle. Why suffer these difficulties when a lighter plough will avoid the adjustment involved and will also be cheaper and more efficient? Many locally made ploughs (Pakistan, Turkey, Jordan, *etc*) are relatively light and work very easily and effectively: thus it is the practitioners who have a better understanding of the fundamental relationship between plough weight and draught. The TIDE endorses the practitioners' viewpoint.

• ***A lighter plough has inherently less draught and is more user-friendly.***

Plough weight and penetration

It is often argued that weight is necessary to get the plough to penetrate to its working depth. The TIDE suggests a more subtle and effective approach - perhaps the e.v.f. is too small? What is the reason? Almost invariably, it is not because the weight (main downward force) is too little, but because support forces are too big. Unwanted support forces can arise under the point of a worn share, if there is insufficient clearance ('pitch', 'suck' or 'down suction') behind the share or sometimes because the lower edges of the mouldboards are pressing down hard on the soil and providing unwanted support along their bottom edges (the mouldboards of ridging bodies are often badly shaped). Look for shiny surfaces underneath the implement - a useful indicator of areas where the soil may be providing too much support.

• ***Lack of penetration is almost always a question of too much support, not a lack of weight.***

The influence of angle of pull on plough draught

The TIDE suggests that the draught of a plough will be reduced as the angle of pull is increased, if the e.v.f. acting on it remains constant. This effect was noted more than 150 years ago by Pusey (1840) who observed the advantages gained from a steeper angle of pull, but found it difficult to find a scientific explanation. Although some successful harness designs feature a steep angle of pull, it has been adopted through *ad hoc* development rather than by intent. The concept is indeed disputed by some specialist advisers.

It has been shown in theory and practice that plough draught can be very significantly reduced by using a steeper

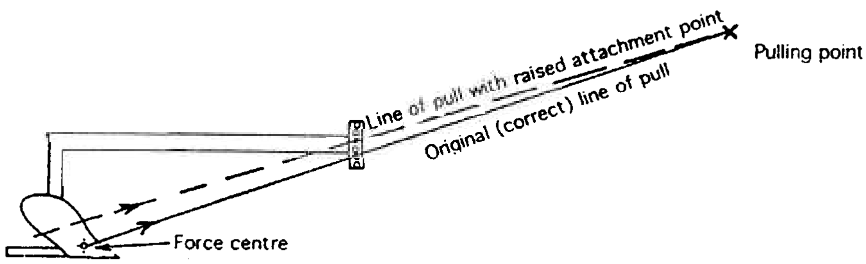
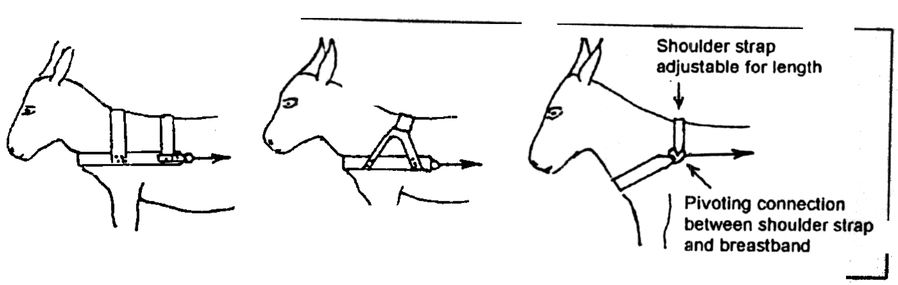


Fig. 7 The effect of raising the point of attachment of the pull chain.

Showing how a raised attachment point reduces the angle of the line of pull but raises its line of action. The new line of pull creates a clockwise turning effect about the force centre, causing the plough to run nose down.

angle of pull. This fact can be used by designers and operators to improve system efficiency.

- ***For optimum results, and ease of control, the plough and harness must be designed as an integrated combination.***



The two illustrations to the left show breast band harnesses with rigid (usually stitched) connections to the shoulder straps - the breastband is held vertical and the top edge tends to dig into the donkey's chest. The right hand illustration shows a breastband harness with adjustable shoulder strap which is free to pivot at its connection to the breastband - these arrangements allow the breast band to be set to the correct height and to take up its most comfortable angle.

Fig. 8 Preferred arrangement for a breastband harness, shown on the right.

Working adjustments to the plough - background

Farmers are often criticised for not using the hake attachment points or other form of regulator correctly, or even for throwing the regulator away and wrapping the pull chain round the plough beam in a permanent position. But perhaps it is the critics who are at fault for not giving good (and often conflicting) advice on adjustment of the point of attachment to the hake? There are two matters to consider: setting the plough into work and changing the depth of work.

Working adjustments to the plough - setting the plough into work

As is well known, the basic principle is to attach the pull chain (or rope) to the hake at the point where the line of pull and the hake adjustment coincide. If the chosen attachment point is not quite correct this will be shown up in work -. the plough will run either nose up or nose down. This can be corrected by a 'fine tuning' adjustment at the hake.

It is suspected that some ploughs are poorly designed, with the hitch points positioned incorrectly so that there is no hitch point available on the line of pull joining the harness pulling point and the plough's force centre. In such cases, the plough cannot be adjusted to run with correct balance and the ploughperson will have to struggle continuously to hold the plough in a reasonable working alignment - this can be an extremely tiring process. Correct design is essential for joyful ploughing.

Working adjustments to the plough - changing the depth of work

Training manuals often state that to increase the depth of ploughing the pull chain should be attached at a higher point on the hake. This does reduce the angle of pull (very slightly) and should therefore increase the draught and depth of work, but unfortunately it also changes the location of the line of pull so that it no longer passes through the force centre ('centre of resistance') of the plough but passes above it to produce a nose-down turning effect *(Figure 7)*.

The manuals then advise that the nose-down movement should be counteracted by lowering the nose wheel into contact with the ground to make the plough run level again. But this produces two contradictory effects. First: the angle of pull is reduced - draught and depth of work should be increased. Second: the wheel develops a support force from the soil - this acts to reduce the e.v.f. and hence also the draught and depth of work. The net effect on depth of work is zero, but the wheel and its bearings are put under load unnecessarily, leading to excessive bearing wear. Plough efficiency is reduced due to rolling resistance of the wheel.

The correct method of adjusting depth of work is by changing the angle of pull and going through the initial setting procedure again using the hake attachment to fine tune the plough for level running.

Working adjustments to the plough - conclusion

So are farmers justified in their suspicion - and often their rejection - of specified adjustment procedures? Are they making a logical response? The answer is probably; "Yes", for two reasons. First: once a correct adjustment is achieved, there is little reason for changing it if the line of pull is not changed - this is only likely to happen if the length of the pull chain is altered or if different draught animals are used which differ significantly in height. Second: the adjustment procedures they have been taught were probably confusing and may have been incorrect. The nosewheel, if used in the way which is often written about and advised, causes a rolling resistance which reduces efficiency. Its only useful function is to assist in turning and transporting the plough but, if this is necessary, the plough is too heavy anyway!

- *The nose wheel (or skid) that is usually fitted to swing ploughs is a heavy, expensive and unnecessary distraction which, if the plough is well designed, is a hindrance to its proper adjustment and control.*

Harness design

A breast band harness was chosen for the experimental work referred to above because, compared with the main alternatives, it is simpler, cheaper and more easily made locally and is therefore more user-friendly and accessible to small scale farmers.

One particular feature of the harness was observed to be particularly helpful to the donkey's comfort in use and can easily be incorporated into other breastband designs. The ability to adjust the breastband to fit comfortably on the animal's chest - not its neck! - was greatly aided by making the shoulder strap adjustable for length and by connecting it to the breastband by a fitting (a ring in this case) which allowed them to pivot relative to each other. This allowed the breastband to be adjusted for height and to sit at an angle to give maximum comfort.

Many existing harness have a rigid stitched connection between the breastband and the shoulder strap (and any backstrap(s) which may be fitted) so that the breastband is held vertically at the chest. The top edge of the breastband then digs hard into the animal - particularly if the breastband is made of rigid material such as transmission belting, which appears to be a favoured material. This is the case with the donkey shown ploughing in the *Title Photograph* obviously not desirable.

The shoulder strap and breastband form the basic assembly used in a breastband harness and *Figure 8* illustrates some of their desirable and less desirable features as mentioned above.

Acknowledgements

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UK farm incomes in 1997

Total Income From Farming, TIFF, which represents the income to farmers, partners, directors, their spouses and family workers, is estimated to have fallen by 35 per cent, or by 37 per cent in real terms. Farming Income, which covers only farmers and their spouses, is estimated to have fallen by 45 per cent, or by 46 per cent in real terms. TIFF remains above the levels of the early 1990s in real terms.

The fall in TIFF in 1997 is largely due to lower prices received by farmers for all major commodities. The relative strength of sterling compared to 1996 has been a major factor underlying the fall in prices.

The value of the agricultural industry's gross output was 11 per cent lower. For cereals the value of output was 15 per cent lower whilst for livestock and livestock products it was 10 per cent lower. The cost of the industry's gross input was 4 per cent lower due to lower expenditure on animal feed.

The value of output of cattle and calves fell by £111 million or 6 per cent. In addition, payments to farmers within the Over Thirty Month Scheme, the Calf Processing Aid Scheme and the Selective Cull were £122 million lower.

The industry's productivity measured in terms of the volume of gross output per unit of all inputs rose by 2 per cent. The volume of output was 0.5 per cent higher whilst the volume of inputs used was 1.3 per cent lower.

Over the year interest rates rose and the industry's interest payments were 12.5 per cent higher. The cost of hired labour rose by 4.9 per cent despite a slight decrease in the overall amount of time worked.

Measures of cash flow, which may reflect more closely the variations in income perceived by farm households, show smaller decreases. In real terms, cash flow for the wider group, which includes directors and family workers, fell by 33 per cent whilst that for just farmers and their spouses fell by 42 per cent. These figures incorporate expenditure on capital formation but exclude the losses due to depreciation of capital assets.