10. Draft assessment and work rates

10.1 Implement draft

The resistance an implement provides to forward movement will determine the draft force animals have to apply to achieve the required work. Draft forces can be measured with various types of *dynamometer* which are commonly based on expanding springs, hydraulic pistons or loadcells (Figs. 10-1, 10-2, 10-3). In section 5.3 it was mentioned that there is now great potential for combining modern loadcells with computers. With such systems draft measurements can be recorded in the field many times each second, and mean values calculated over specific distances or periods of time (Lawrence and Pearson, 1985).

The draft of an implement will be determined by many factors related to its specific design, including:

- overall weight;
- overall shape;
- shape of its components, including the sharpness of any cutting elements;
- angle(s) at which components meet the soil or working surface;
- position and angle(s) of attachment of traction chain or drawpole;
- material of which the implement and its components are made;
- adhesion properties of working surfaces;
- working width;
- working depth;
- friction within any rotating or articulating parts;
- elasticity/rigidity of different members.

As many of these details (e.g. working depth and width) can be adjusted, the draft will depend on particular settings and therefore on the operator. The operator may also vary working width, depth or angle of work as an implement is used, and such on-the-move adjustments through variations in pressure on the handles can be subtle or very significant.

There are also numerous external factors that influence the draft requirement of implements. These are specific to the particular environment and the precise conditions under which equipment is used. They include:

- type and composition of the soil;
- soil moisture;
- previous tillage history;
- quantity and type of living plants growing in the soil;
- quantity and type of crop residues and trash;
- presence of roots, stones or stumps;
- slope of the land.

The draft of an implement may increase with the speed at which it is pulled, although at normal animal walking speeds, this source of variation will be slight. The implement speed will itself depend on many factors relating to the type and condition of the animals.

A diagram illustrating how some of the factors determining draft are interrelated was provided in Chapter 2 (Fig. 2-3) and the international unit of force, the newton (N), was also explained in Chapter 2. For more technical details on the dynamics of soil tillage, readers are referred to texts such as that of Kepner, Bainer and Barger (1978), although these authors noted that tillage is still far from being an exact science.

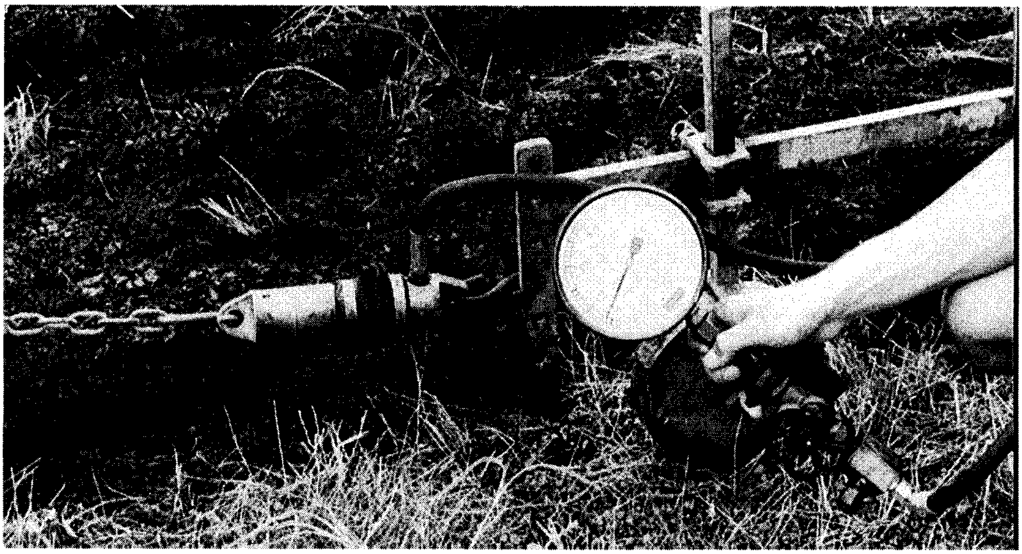
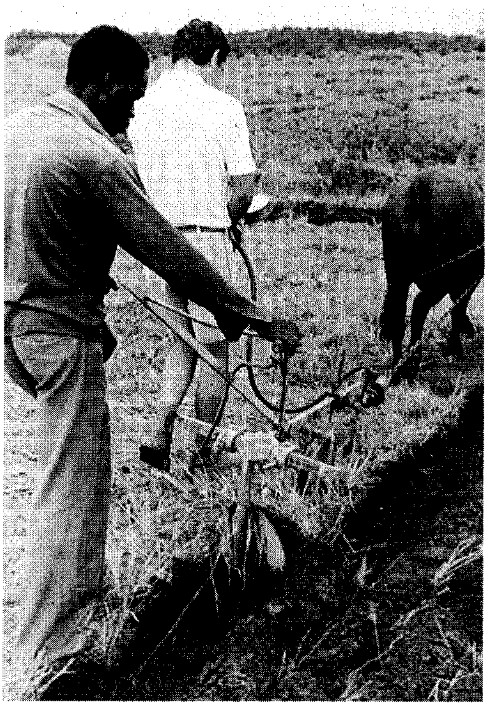


Photo: Paul Starkey

Fig. 10-1: A hydraulic dynamometer used for measuring draft forces.

Fig. 10-2:The use of a hydraulic dynamometer to assess the draft of a Houe Sine plow in specific environmental conditions in Sierra Leone.

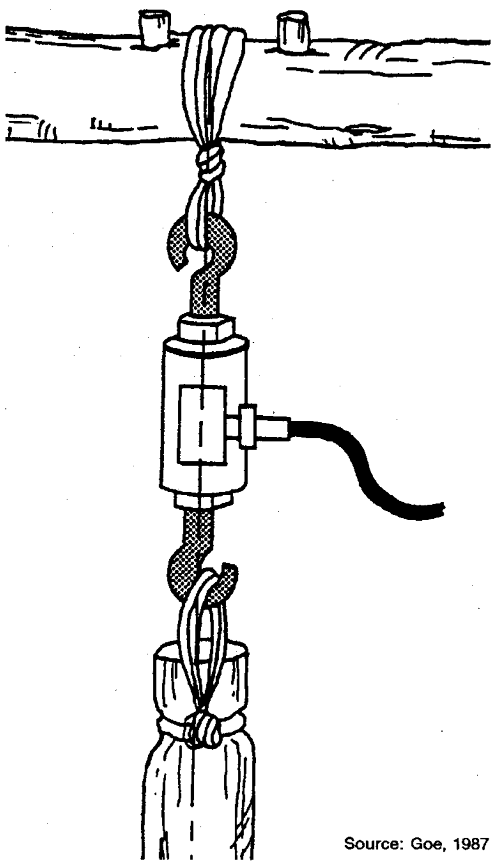
Photo: Paul Starkey



In practice the draft force that animals exert to draw an implement constantly changes due to numerous interacting variations attributable to the animals, the operator, the soil and the orientation of the implements. Lawrence and Pearson (1985) reported that in one experiment the actual draft measurements ranged from 589 to 2160 N for the same plow in the same field in the same two week period at the end of a rainy season. If this degree of variation can exist in one field within the same climatic season, the potential for differences between different soil types and between seasons is quite staggering. O'Neill and Kemp (1988) gave examples of the great variation in draft forces associated with soil conditions and previous tillage history. In trials in India the mean horizontal draft forces of a blade harrow (bakhar) pulled by a pair of oxen ranged from 239 N in a soil that was dry but which had been previously plowed, to 1227 N in moist soil with many weeds. It should be stressed that this fivefold difference was in overall *mean* draft in nominally "steady-state" conditions (the mean was itself derived from a whole series of 15-second means, each one obtained from 450 force measurements). The range between maximum and minimum instantaneous draft forces would have been far greater than this. Furthermore the trials were undertaken under what were considered "normal" and representative cultivation conditions, and so even this very wide range does not indicate the extremes of draft force that might be recorded for such implements under different conditions in India.

It is therefore evident that to simply state that one particular design of mouldboard plow has a draft of (say) 700 N has little meaning by itself. That plow might be used with the depth wheel set just above the level of the share (for very shallow plowing), in light, moist soil with the traction chain attached to the unplowed side of the hake. The same implement could also be used with the wheel raised for deep plowing, in a dry, sunbaked Vertisol (black cotton soil) with the traction chain towards the furrow. In the first instance the draft could be managed by a single donkey, in the latter it could be hard-going for a team of six oxen. Thus absolute figures relate only to the highly specific conditions of use at any one time.

If the draft of different implements is to be measured, the readings should be obtained from comparable settings of the various implements pulled by the same animals operating in the same external conditions. Useful comparisons of draft requirements can also be made if each implement is used in a number of different settings in the same conditions. In such circumstances the environmental variables are *relatively* constant. Where possible trials should be replicated and randomized both to facilitate analysis and to reduce the risk of unintentionally linking the performance of one implement or setting with one environmental, animal or human variable. Not all of the possible sources of variation are obvious. For example Pearson *et al.* (1989) provided figures illustrating how much effect individual operators can have on the draft of



Source: Goe, 1987

Fig. 10-3: Diagram showing how an electronic loadcell (strain guage) dynamometer was used to join the beams of a maresha ards to withers yokes during research studies in Ethiopia.

an implement, even one with fixed settings; in one particular trial plowing terraces with a traditional ard in Nepal, a plow had a mean draft of 704N with one plowman, and 492N with another. In this case the animals, soil, environmental conditions and apparent working practices were the same, so that the differences in draft could only be ascribed to the way the two operators used the plows. One plowman preferred the animals to walk faster than the other, and it appears that to facilitate this he must have consciously or subconsciously varied the working depth and/or orientation of the plow, so reducing its draft.

Table 10-1: A selection of assessments of force, speed and power reported in the literature. ***Important note:*** *These figures were collected under diverse environmental conditions and encompass very different standards of accuracy, repetition and scientific rigour. The information is provided for illustrative purposes only, and detailed comparisons between the various frames without reference to the original sources is* ***not*** *advised. Some figures have been recalculated from different units or data forms used in the sources. (WTC = wheeled toolcarrier)*

Country	Animals	Conditions	Implement	Force (N)	Speed (m s^{-1})	Power (W)	Reference
Botswana	400-600kg oxen (team of four oxen)	On-station; loose sandy-loam soil, after first rains	30 cm plow	2318	1.08	2498	Bordet, 1987; AFRC-Engineering, 1987
			25cm plow	1776	1.02	1802	
			5-tine cultivator	1220	1.17	1417	
			rolling cultivator	852	1.31	1086	
			FMDU ripper	2039	0.75	1533	
			CEEMAT tine	962	1.12	1086	
Burkina Faso	400kg W. African Zebu (pair)	On-station; dry sandy-clay soils	Prototype tine cultivator - RR	800	0.8	640	Le Thiec and Bordet, 1988
Ethiopia	250-320kg Ethiopian Zebu oxen (pair)	Farmers' fields after:	Maresha ard plow				Goe, 1987
		long fallow		1195	0.35	424	
		short fallow		928	0.55	510	
Ethiopia	Single oxen: Ethiop'n Zebu	Farmers' fields. Nutrition levels:	Maresha ard plow depth:				Abiye Astatke, Reed and Butterworth, 1986
	309 kg	Normal	13.9cm	590	0.5	300	
	302 kg	Underfed	13.9cm	600	0.5	310	
	Boran × Zebu						
	372 kg	Normal	14.6cm	660	0.5	330	
	465 kg	Underfed	14.6cm	710	0.5	360	
Ethiopia	400 kg Ethiopian Zebu oxen (pair)	Experimental station	Loading cart	422	0.6	220	Kebede and Pathak, 1987
				775	0.5	380	
				1060	0.4	400	
				1373	0.3	360	
Morocco	270kg horse	On-station; level vertisols, winter rains	20cm plow	795	1.23	978	Bansal, El Gharras, and Hamilton, 1989
	460kg mule			923	1.06	978	
	420kg camel			569	1.04	591	
	270kg horse harnessed with 175kg donkey		20cm plow	790	0.9	711	
			Morocco ard	636	1.16	738	
			WTC, 22cm plow	729	1.13	824	
	420kg camel harnessed with 175kg donkey		20cm plow	795	1.04	827	
			Morocco ard	550	0.92	506	
			WTC, 22cm plow	657	0.92	604	
Niger	140kg donkey	On-station; indicative figures only	Loading sledge	220	1.1	240	Betker and Klaij, 1988
			Braking device	400	1.0	400	
	300kg horse		Loading sledge	700	1.3	910	
			Braking device	3700	1.5	5600	

Country	Animals	Conditions	Implement	Force (N)	Speed (m s-1)	Power (W)	Reference
Costa Rica	475kg Rojo Criollo oxen (pair)	On-station; heavy soil, fairly dry	WTC plow	1131	0.59	670	Lawrence, 1989
			WTC mower	634	0.59	368	
			WTC cart	214	1.0	211	
China	300kg yellow cattle (single)	Not stated	Plow	650	0.7	550	Feng Yang-lian, 1984
			Cart	420	0.9	378	
India	530kg Malvi oxen (pair)	On-station; heavy black soils	15cm plow	550	0.73	380	Rautaray, 1987
			90cm disc harrow	500	0.76	402	
			45 cm blade harrow	600	0.64	373	
			WTC with:				
			15cm plow	700	0.77	530	
			25cm plow	1200	0.53	604	
			2 × 15cm plows	1500	0.49	709	
			2 × 25cm plows	1950	nil	nil	
	740kg Red Dane/ Sahiwal crossbred oxen (pair)		WTC with:				
			15cm plow	700	0.79	552	
			25cm plow	1200	0.65	746	
			2 × 15cm plows	1500	0.51	880	
			2 × 25cm plows	1950	0.57	1100	
India	435kg (mean) oxen (pairs)	On-station; experimental track	Loading sledge:				Premi and Singh, 1987
			First hour	840	0.96	798	
			Sixth hour	840	0.71	589	
India	Oxen (pair), (weight not stated)	On-station	Load sledge pulled with:				Ayre, 1981 after Swamy-Rao, 1964
			pole yoke	2830	0.28	790	
			collar-yoke	2820	0.33	900	
	Single ox (weight not stated)		15cm plow pulled with:				
			back harness	620	0.75	450	
			collar-yoke	650	0.84	540	
Nepal	250kg oxen (pair)	Hill terraces, after main rains;	Ard plow (traditional)				Pearson, Lawrence and Ghimire, 1989
		Plowman K		704	0.33	232	
		Plowman R		492	0.49	241	
Nepal	Pairs of:	Terai rough roads and farm tracks	Wooden carts				Pearson, 1989
	280kg buffaloes		380kg load	300	1.0	300	
	390kg oxen		587kg load	336	1.0	336	
Thailand	Buffalo (nos and weights not stated)	On-station	340kg sledge pulled with:				Garner, 1957
			single yoke	1480	0.27	400	
			collar	1480	0.40	592	
			breast band	1480	0.45	666	

Photo: AFRC-Engineering archives

Fig. 10-4: Use of AFRC-Engineering computer-based data-logger during trials in Ethiopia.

In most other cases the different effects of implement and environment on the draft measurements are very difficult to distinguish. For this reason Lawrence and Pearson (1985) cautioned against ascribing "typical" values to draft forces unless the numerous environmental variables had been rigidly defined.

Table 10-1 provides some examples of implement force, speed and power found in the literature. From the foregoing discussion it should be clear that these should be considered as "illustrative" figures and, since they are cited here away from their original context, they should be viewed with great caution. The data presented were collected in diverse environmental conditions, over various periods of time, with very different levels of precision and statistical analysis (if any). Some of the data refer to short-term tests in which animals were expected to work very hard, while others are derived from average figures over working periods in excess of five hours. For these reasons it would be most unwise to make specific comparisons between the different sources. It is more acceptable to make general and superficial comparisons between the different variables that were assessed by the same source, for example the effects of different implements, animals, harnesses, management systems and people. However it must again be stressed that these figures have been extracted from their original context in which the experimental designs or levels of statistical significance (if any) were explained and so readers are strongly urged to refer to the original publications before quoting such figures or drawing any conclusions.

10.2 Working rates

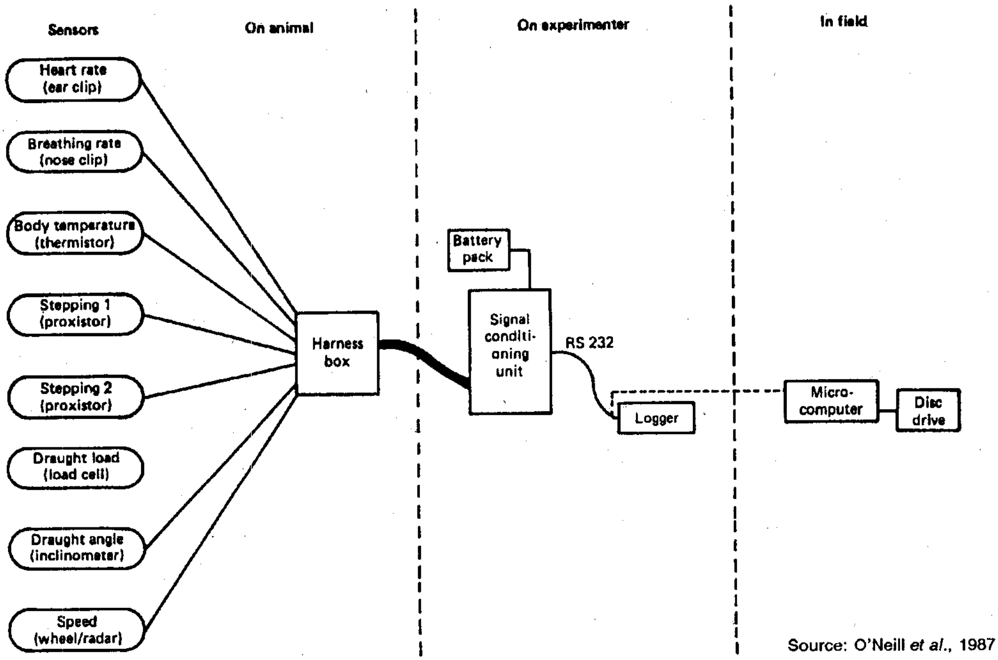
It was noted in Chapter 2 that work is a product of the force applied (approximately equivalent to implement draft) and the distance moved. The rate of work (power output) depends on the quantity of work (draft x distance) and the time in which this is achieved, which is determined by the average speed at which the animals move. Some of the numerous factors that interact and influence working rate were illustrated in Fig. 2-3.

Implement draft force depends on many things (briefly discussed in the previous section) including implement size, shape, weight, width of work, depth of setting; soil type, moisture content, tillage history; vegetation quantity and quality; environmental obstacles, stones, stumps and roots; land slope.

The distance and speed moved depends greatly on the characteristics of the animals used: their species (different species have characteristic walking rates), their weight, size, strength, condition and their standard of training. The power output of an animal may be influenced by its past history (nutrition, disease, body condition, training, recent work experience) and its immediate environment (temperature, relative humidity, sunshine, ground surface). Different species and individuals may react to the environment in diverse ways. Some animals are better able (or willing) to withstand disease challenges or environmental extremes such as high air temperatures, bright sunshine or deep mud than others. Humped cattle (*Bos indicus*), with very effective temperature regulation systems, are often able to work longer in hot conditions than humpless cattle (*Bos taurus*). Water buffaloes have relatively inefficient temperature regulation systems so that "over-heating" during prolonged heavy work is a problem, one traditionally solved when animals are allowed to wallow in water (Bakrie, Murray, Hogan and Kennedy, 1987; Pietersen and Ffoulkes, 1988; Pearson, 1989).

Farmers and research scientists have frequently observed tremendous differences in the apparent working abilities of animals of the same size and same species carrying out the same operation under similar conditions. (To put this in perspective: the animals might well draw the same conclusion about humans!). Some animals may rush and tire, some may be "slow starters" reaching peak work late in the day, and others seem to plod at the same rate whatever the time of day or environmental conditions. While farmers (and researchers)

Fig. 10-5: Diagram illustrating AFRC-Engineering computer-based data-logger system.



Source: O'Neill *et al.*, 1987

Fig. 10-6: Measuring draft and work output in Nepal using a CTVM ergometer. The wheel trailed by the ard plow measured distance travelled. Wires from the loadcell and body sensors passed to a micro-processor (carried in a traditional head-basket in this case). Among other things, this study highlighted how different plowmen affected draft, speed and work rates.

Photo: Anne Pearson

may well describe such animal work characteristics with varying degrees of admiration, contempt and colourful language, there are few objective ways of assessing differences in temperaments and mood. Such differences between working animals may be the result of complex physiological and/or psychological interactions between the animal and its environment over many years, including influences of previous training, disease, nutrition, work history and human company.

An interesting example of the influence of animal psychology on work rates is the observation that animals walk faster and have a higher work output when they are walking in the general direction of their "home" than when they are walking away from it; thus irrespective of field orientation and slope, plowing may well involve alternate "slow" furrows as the animals face away from the farm, and "fast" furrows as they move towards it. Pearson (1989) reported a similar effect during long-distance carting trials in Nepal when all animals slowed down before, and speeded-up after, the turning that marked the most distant part of the five-hour, 16 km route. Such behavioural patterns can either be reinforced or counteracted by the operator, depending on human temperament or prevailing mood. Some animals, including some N'Dama oxen, seem to be able to set their own very clear working limit. After this apparent limit has been reached it has been observed that neither coaxing and persuasion nor shouting and beating seem to stimulate significant additional work (Starkey, 1981). Other animals, notably long-suffering donkeys, seem to be able to carry on working even when clearly exhausted, an attribute all-too-frequently exploited by humans.

The effect of acute forms of disease is obvious: an animal that is sick is unlikely to work well, and farmers know that working an animal that is unwell may exacerbate the illness. Milder or sub-clinical conditions that are not apparent from visual inspection, may also have a significant effect on work rates. An example of such a case was provided by Pearson (1989) who found that two apparently similar and healthy pairs of buffaloes in Nepal had different work performances. On investigation it transpired that the animals that were less able to work, and which eventually had to be laid-off for some days of rest, were anaemic. There were no visible disease symptoms, but there was apparently some parasite (perhaps liver fluke) or condition that was causing anaemia and reducing work potential. In Africa, working animals may be challenged by numerous intestinal and blood parasites, including (in some areas) trypanosomiasis and tick-borne diseases. Little reliable data exists on the occurrence of subclinical diseases in working animals, nor on the effects these may have on work, but it seems reasonable to assume that such conditions may have a significant influence on the ability or willingness of individual animals to maintain a particular rate of work.

Human skills play a major role in establishing the rate at which work is achieved, by determining the effective draft of the implement, and by greatly influencing the walking speed of the animals and the number and length of rests and stoppages. As was mentioned in the previous section, Pearson *et al* (1989) found that during trials involving the plowing of terraces with traditional ards in Nepal, different plowmen tended to work the same animals at different speeds even when the environmental conditions were identical. Human practices may range from the single farmer effectively using only voice commands to encourage animals to walk at a brisk speed or pull a heavy load, to the violence and intimidation evident when up to four people attempt to beat animals into working faster.

Changing the working depth or width of an implement can have both simple and complex effects on work rates. Increases in working *depth* increase implement draft, and this causes animals to slow down and tire more quickly. This slows the overall speed of operation (and also changes the *quality* of work). Changes in the working *width* of an implement are more complex since they can affect working rates in two different and opposite ways. Increasing the working width means that fewer passes are needed to cover each square metre or hectare of land; thus *at constant speed* increasing the working width also *increases* the rate of work. However as the effective width of an implement increases, so does its draft, and this may cause animals to slow down, particularly if the work is already quite hard. In extreme circumstances increasing the working width may cause work to stop altogether as animals become unable or unwilling to pull the implement further. Clearly in any one location, the optimal working width to maximize work output will change with different environmental conditions and the status of the animals.

While there is a positive correlation between the number of animals employed and the rate of work, the relationship is not always simple. As was noted in Chapter 2, at very low implement drafts, a single animal can work at the same rate as a team, simply by pulling the implement at normal speed. In such circumstances doubling or quadrupling the number of animals will make no significant difference to working rate, at least for the first few hours. However at higher implement draft, the single animal will slow down, while a team will be able to walk at normal speed and so work at a faster rate. If one pair can cope with a draft at normal walking speed, coupling an extra team will have no effect in the short term. However an extra team should allow an implement with even higher draft to be pulled at normal walking speed. The use of more animals per implement should allow working speeds to be maintained for longer periods each day or each week. Multiple hitching was discussed in Chapter 3 (section 3.6), where it was pointed out that in small fields two teams of two may be more efficient than one team of four, due to the greater manoeuvrability of small teams.

A large number of other factors may also affect working rates, including the way in which animals are harnessed, the field shape, contours and obstacles, the weather, the time of day and the way in which these influence the

Table 10-2: A selection of assessments of draft force, work-rates and force as a percentage of bodyweight reported in the literature. (WTC = wheeled toolcarrier; BBF = broad-bed and furrow)
***Important note:** These figures were collected under diverse environmental conditions and encompass very different standards of accuracy, repetition and scientific rigour. The information is provided for illustrative purposes only, and direct comparisons between the various frames without reference to the original sources is **not** advised. Some figures have been recalculated from different units or data forms used in the sources.*

Country	Animals	Conditions	Implement	Force (N)	Work ($m^2 h^{-1}$)	Work ($m^2 d^{-1}$)	Force/ weight	Source
Burkina Faso	400kg West African Zebu oxen (pair)	On-station; sandy-clay, early rains	25 cm plow 5-tine tillage		588 1250	2352 5000		Herblot, 1982
Ethiopia	250-320kg Ethiopian Zebu oxen (pair)	Farmers' fields after: long fallow: short fallow	Maresha ard plow	1195 928	199 222	424 510	23% 17%	Goe, 1987
Ethiopia	Single oxen: Ethiop'n Zebu 300 kg Boran × Zebu 372-465 kg	Farmers' fields	Maresha ard plow depth: 13.9cm 14.6cm	595 685	220 242	920 998	20% 24%	Abiye Astatke, et al., 1986
Kenya	310kg zebu oxen (pair). 385kg Friesian × Sahiwal oxen (pr)	On-station; rainy season	Mouldboard plow/weeder (averages)	968 885	720 730	2860 2910	16% 11%	Tessema & Emojong 1984
Madagascar	325kg Zebu oxen (pair)	On-station	Plow	811	0.69	560	12.5%	Scherrer, 1966
Morocco	270kg horse 460kg mule 420kg camel	On-station, level vertisols, winter rains	20cm plow	795 923 569			30% 20% 14%	Bansal, *et al*, 1989
Senegal	400 kg W. African Zebu oxen (pair)	On-station; "General" values	WTC with: Seeder (2 row) 120 cm weeder G'nut lifter (1) G'nut lifter (2)	450 600 450 750	1428 1250 770 1111		6% 8% 6% 9%	Nourrissat, 1965: Monnier, 1965
Sierra Leone	260kg N'Dama oxen (pair) 290kg single ox	Flooded swamp On-station, gravelly soil, rainy season	20 cm plow 17 tine harrow 20 cm plow 3-tine weeder	700 850 650 600	300 500 400 1100	900 1500 2000 2200	14% 16% 13% 21%	Starkey, 1981
Thailand	270kg swamp buffalo (single): No supplement Feed supplement	On-station, rainy season, rice fields	Local wooden beam, mouldboard plow		972 1215	3900 4900		Konanta *et al*, 1986

Country	Animals	Conditions	Implement	Force (N)	Work ($m^2 h^{-1}$)	Work ($m^2 d^{-1}$)	Force/ weight	Source
Bangla-desh	250kg oxen (pair)	On-station	Ard at 12cm	343	680		7%	Barton, 1988
	245kg single ox		Ard at 10.6cm	231	660		9%	
India	530kg Malvi oxen (pair)	On-station; heavy black soils	15cm plow	550	309	2165	10%	Rauta-ray, 1987
			90cm disc harrow	500	1814	12710	9.5%	
			45 cm blade harrow	600	731	5120	11%	
			WTC with:					
			15cm plow	700	365	2550	13%	
			25cm plow	1200	392	2745	23%	
			2 × 15cm plows	1500	496	1490	28%	
			2 × 25cm plows	1950	nil	nil	37%	
India	450kg Hallikar zebu oxen (pair)	Vertisols; on-station BBF system; plowing & ridging after previous harvest; other operations during rains	Tropicultor					Bansal and Sri-vastava, 1981
			WTC with:					
			22cm plows (2)	2300	4000		25%	
			Ridgers (2)	1830	4000		20%	
			Harrow tines	1600	2272		18%	
			Bed former	1850	3030		21%	
			Planter	1020	3333		11%	
			Weeding tines	1120	2500		12%	
UK	885kg Hereford/Friesian oxen (pair)	On-station	180cm harrow	2000	4633		11%	Barton, 1985

prevailing moods of the people and the animals. In practice the work rate at any particular time and place will depend on a unique set of variables. This clearly makes comparisons of rates for different operations, implements, animals, soils, seasons or locations very problematic.

A further problem of comparing work rates is the variable interpretation of what actually constitutes work time. The rate at which an operation is actually being performed can be calculated quite easily if animals are timed, and output assessed (e.g. area covered = distance × working width). Such "actual working time" calculations have the advantage of ignoring time lost by apparently spurious local factors (such as negotiating obstacles, untangling caught traces or even major implement breakages). Nevertheless figures which ignore such wasted time are very unrealistic, since numerous "spurious" factors do occur, and do affect the work of a farmer. Realistic work times should include the *idle* times due to clogging, resetting and breakages. They should also include the *incidental* times of end of row turning, which are affected by many factors including the manoeuvrability of the implement, the shape of the plot and the number and proficiency of animals and people.

On-field *rest* times for people and animals can also be considered a component of realistic work rates; the number and length of rests may directly influence the rate at which work is carried out between rests. Data have been collected that support the idea that short rests, perhaps of only a few seconds such as those at the end of a row, are actually crucial in allowing animals to work steadily and keep

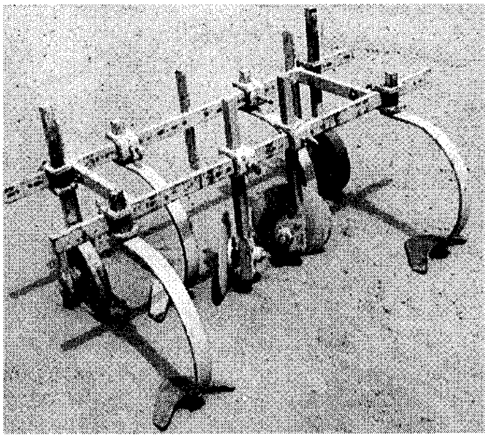


Photo: Paul Starkey

Fig. 10-7: Prototype intermediate toolframe that was developed for maize cultivation in The Gambia. While quality of work appeared good, factors affecting work rates (in comparison to the alternative, lighterweight, simpler Houe Sine toolbar) included: wide working width (faster); heavy draft (slower speed, more rests); low manoeuvrability and heavier weight (slower, longer time at turns, longer transport time from village to field); more complicated adjustments (slower, longer set-up time). In general the design was considered by farmers as "too heavy" and it did not develop past the stage of multi-locational on-farm testing.

their metabolic processes below stress levels (Kemp, 1989). Pearson (1989) noted that although buffaloes and cattle could walk at the same rate when carting over distances of 16 km, with loads of 500 kg, buffaloes had to rest and wallow every few hours to bring down their body temperature, which could rise markedly during work. Since the cattle did not need to rest during the work, their effective work rate was higher, and they were to be preferred in cases where time was of the essence. During trials in Costa Rica it was found that oxen performing "heavy work" (plowing with 1100N draft) only worked 77% of the "working time", while they worked 90% of the time when performing medium work (mowing with 600N draft) and 96% of the time when undertaking light work (carting with 214N draft) (Lawrence, 1989).

The time required for *preparation*, including the harnessing of animals and the *setting-up* and adjusting of equipment may also be considered part of the actual work. This is particularly important if the work rates of simple and complicated implements or harnessing systems are being compared, for time-savings on the field may require longer preparation times, and thus lower overall savings in time. Low adoption by farmers of three-pad harnesses for cattle, wheeled toolcarriers or precision seeders may be partially explained by longer preparation times. Finally it may be appropriate to include *travelling* time as part of the work. Naturally this will depend largely on the distance between farmers' homes or animal enclosure, and their fields as well as the nature of the path and terrain. However it will also be related to the ease of transport of the implement, and the nature and training of the team. The importance of travelling time may become particularly apparent when lightweight and heavy implements are compared in areas where field paths are narrow.

Agricultural engineers sometimes use the concept of *field efficiency* to compare different implements and working practices. Field efficiency is calculated as actual rate of work (also known as *effective field capacity*) as a proportion of theoretical rate of work (or theoretical field capacity). The theoretical rate assumes non-stop work, with no time at all lost in turns, rests or adjustments. The idea of field efficiency can be useful for comparing two implements, harnesses or working practices operating in identical conditions, for it highlights the importance of "time losses", that occur during manoeuvring or clogging. However while a theoretical, constant workspeed over several hours is not beyond belief for tractors that never tire, a similar concept for working animals begins to become absurd. Since the work rates of animals are so context-specific and the interpretation of "work time" so variable, field efficiency figures relating to draft animals can only be realistically compared if they derive from the same source.

It is apparent that realistic assessment of working rates requires information based on actual farmer experience, and this may be obtained with the help of enumerators, or simply by asking the farmers. In a detailed study in the Ethiopian highlands Goe (1987) cross-checked work actually timed by enumerators with estimates made by farmers who did not own watches. Farmers' estimates were generally slightly greater than the chronological records, but were within the standard deviation of the recorded times.

Having recorded the area worked and the overall time taken, one can obtain a figure for the work rate in terms of area per unit of time (e.g. square metres per hour), or in time per unit of area (e.g. hours per hectare). However a further complication is that farmers and animals may only be prepared to work a limited number of hours per day, and days per week. Thus an effective rate of 24 hours per hectare does not mean that one hectare could be cultivated in three 8-hour working days. In one farm survey, Ethiopian farmers often plowed for 7 hours a day, but they did not work with their animals for more than three consecutive days or more than four days a week (Goe, 1987). Elsewhere farmers may only work their animals three to four hours a day, with a day (or two) off every third or fourth day. Under such regimes, 24 hours of work might well take up to two weeks to complete. This has particular implications for operations in which timeliness is crucial. For example, where manual labour is readily available, operations using hand implements may well be completed *earlier* than if animal-powered equipment is used, even though the animal-powered work rate is much *faster* than the manual rate. Another factor to consider is that work rates seldom specify the *quality* of work achieved, although this is vital in assessing the comparative advantages and disadvantages of equipment and techniques.

It should be apparent that working rates determined entirely on research stations are likely to be very different from those achieved by farmers. The effects of preparation, travelling and turning times are proportionately greater in small fields and small farms than they are when large areas can be worked at one time. Whether or not a farmer eventually selects a particular piece of equipment will depend not on optimal figures but on the working rates achieved in reality. This may explain why some useful equipment, apparently capable of improved work-rates, has been rejected by farmers.

Photo: J. Rauch

Fig. 10-8: Adjusting a locally made wheeled toolcarrier in Zambia. Adjustment and repair times are an integral part of normal work, and these should not simply be ignored during research trials.

One useful application of information on work rates is for preselecting equipment types for possible farmer evaluation. By comparing the working rates of different designs with each other, or with manual alternatives, an early impression may be gained as to whether an implement is likely to be cost-effective. In assessing published figures, it is essential to understand that they will have been obtained in unique circumstances, and it is important to clarify in one's mind the prevailing conditions (animals, soils, people, equipment, etc.). It is also crucial to be aware of what particular definition of work rate was being applied, with what degree of accuracy it was being

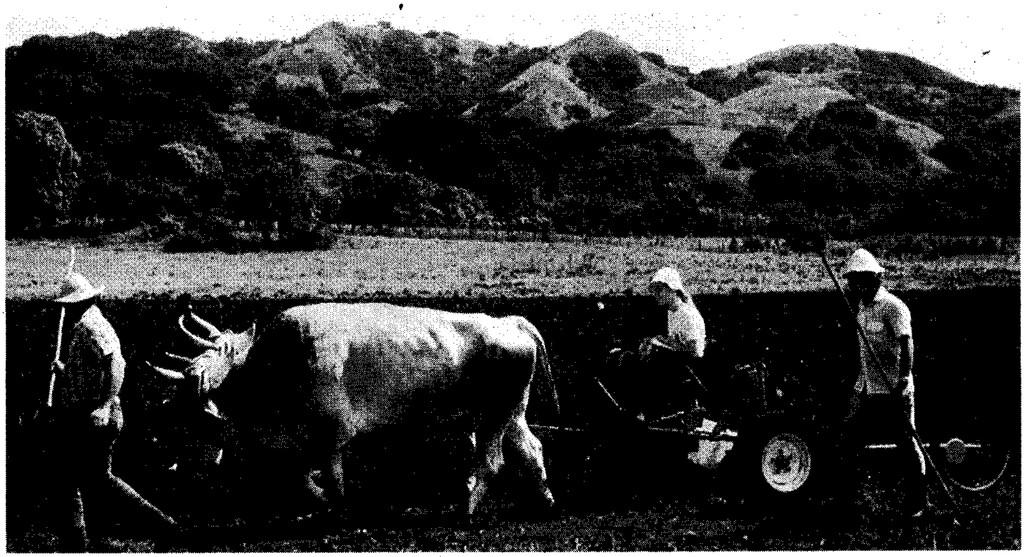


Photo: Peter Lawrence

Fig. 10-9: Measuring the force, distance, and work output of oxen during trials in Costa Rica

measured and over what period of time. In Table 10-2 some examples of work rates extracted from a range of publications are presented. The figures cited differ greatly in the circumstances under which they were obtained, the definition of "work time", the precision of measurement and the degree of replication, randomization and statistical analysis (if any). Thus the table as a single entity should be treated with great caution. While figures from the same source may be broadly comparable, it would not be wise to compare data from different sources without referring to the original publications for comprehensive details of the location, duration and conditions of the trials.

In conclusion, the concept of agricultural "work rates" should, as far as possible, refer to the combined actions of the whole working team (human-implement-animal). Although specific research studies may require concentration on individual elements and short-term measures of components, these should be *interpreted* from a farmer's perspective. Farmers' work rates have to be appropriate to their specific farming systems, including their animals, field conditions, cropping patterns, economic and labour resources and their social aspirations. When undertaking a field operation a farmer usually has to walk at the same speed and for the same distance as the animals, and there may be occasions when a long but easy walk is preferable to a slow, hard slog; the need of animals for specific rests may coincide with similar desires in farmers. For some farmers in certain situations speed of operation and timeliness is crucial, and rapid operations can greatly affect final harvest. In other circumstances factors such as operator convenience and even outward "appearances" may be more important to the farmer. Even where speed is critical for the farmer, it is likely that the *overall* rate of work that can be achieved per day, per week, per season, per animal or per field will be more important than apparent "hourly rates".

10.3 "Light" and "heavy" work

Farmers and research workers are well aware of the obvious differences between work that is "light" or "heavy" but while such terms can be useful descriptors, there is a risk if these terms are used to oversimplify situations that are actually very complex. In particular there are potential dangers if simple assessments of draft force or short-term power output are used to estimate whether the actual work that animals perform in a day is "light" or "heavy". Some people have attempted to estimate work output and energy expenditure from draft force figures alone, and for simplicity have assumed constant speed irrespective of draft and time. More commonly power output has been assessed by multiplying walking speed and draft force, with work being computed as a product of power and time. Such calculations alone may not give a true picture if they do not take account of significant variations in animal speed, rest periods and the distance that the animals move.

It has for many years been generally assumed that animals pulling heavy loads inevitably use more energy in a day than those pulling light loads, and this had led to detailed recommendations as to different levels of daily nutrition required for "light work" and "heavy work" (CEEMAT, 1971; CEEMAT/FAO, 1972; Reh, 1982). However in trials in Costa Rica it was found that, during the course of a 5.5 hour working day, animals performing light (carting with 200N draft), medium (mowing with 600N draft) and heavy (plowing with 1100N draft) operations actually used very similar amounts of energy, as calculated from work done, distance travelled and height ascended while working (Lawrence, 1989). This rather surprising result was explained as follows. Although the animals "working hard" were pulling a draft *five times* greater than when they had light work, they walked more slowly, at only 0.6 m s^{-1}, compared with 1.0 m s^{-1} when they pulled a light load. As a result their mean power output during actual "heavy" work was *three times* (not five times) that of the light work. Oxen took more rests while working hard and only actually worked 77% of the time, compared with 96% of the time when performing light work. Furthermore the animals performing heavy work walked 8.9 km during the 5.5 hour working day, while those undertaking light work walked 19 km. The energy required for this walking was very significant: at the end of the standard working period the oxen that had pulled little but walked far, had often used up *more* energy than those that had worked hard over a shorter distance. Consequently, in this instance, the animals that had undertaken "light" work would have required at least as much food as those doing "heavy" work just to replace the energy used (Lawrence, 1989).

The energy the animal uses in walking has not generally been included in comparisons of work output for farm operations and would not be apparent from standard measurements of power output. Nevertheless it is clearly important, since it has a significant effect on the nutritional requirements of an animal, perhaps accounting for about one third of all energy expenditure during medium plowing and two thirds during carting along roads (Lawrence, 1985). In very muddy conditions, an even greater proportion of animal energy may be used simply in walking, for the energy cost of walking in 300 mm of mud may be almost double that in normal conditions (Lawrence, 1987).

As a result of their research in Costa Rica, Nepal and at CTVM, Lawrence and Pearson (1990) argued that actual work output of animals is limited by the overall rate at which animals are able, or willing, to expend energy for *all purposes*; that is not only for tractive pulling but also for walking, carrying and ascending slopes. According to Lawrence and Pearson, the energy that an ox can expend in a given period is dependent on its weight and the duration of work and ranges from 0.9 MJ per 100 kg bodyweight per hour for a 800 kg animal working eight hours to 1.7 MJ per 100 kg bodyweight per hour for a 200 kg animal working only one hour. These authors provided a table that allows such estimated energy availability to be read-off easily. They also provided an equation that could make use of this "energy availability" information to predict the distance an ox could reasonably be expected to walk in a given time (and therefore the work it could perform), assuming the "average" draft force was known. The equations was:

$$d=\frac{300E}{F+0.6M}$$

where d = distance travelled (km), E = energy available for work (MJ), F = average draft force (N) and M = weight of the ox (kg).

The authors note that when using such an equation, many variables have to be assumed to be constant, and that should the condition of the animal(s) or environment be less than ideal, predictions can be out by over 40%. Lawrence and Pearson readily admit that while their equation may be one of the most accurate means that *scientists* have at present for predicting work output, an experienced *farmer* might well be more accurate at assessing actual work, not in megajoules, but in farmers' own terms ("That pair of animals could plow that field in these conditions in three and a half hours").

The whole subject of draft animals, their energy utilization, working abilities and nutritional requirements is due to be covered in another book in this series, and so will not be discussed here. It is accepted that it is rather unsatisfactory to consider the different aspects of animal-implement combinations in separate volumes, particularly as an integrated approach to animal-implement-farmer combinations is being encouraged. However the separation of "animals" and "implements" has allowed the individual volumes in this series to be more manageable in size, and it is to be hoped that the books will be used together. In the context of the present discussion then the conclusion is simply that it can be dangerous to concentrate on work rates expressed only in terms of the implement interacting with the environment, for this may neglect essential information about the animals themselves, the total work they are doing and what they can realistically achieve in a given period of time.

10.4 "Average" power and "reasonable" work rates

Hopfen (1960; 1969) provided tables entitled "Normal draught power of various animals" and "Draught requirements of some farm implements for operations on medium loam soils". These figures have subsequently been quoted in other publications, although the weights of the animals (500-900kg for oxen and 400-700kg for "light" horses) are different from those commonly found in the tropics. A summary of the research trial results of Scherrer (1966) in Madagascar and West Africa were quoted in CEEMAT (1968, 1971); the CEEMAT publication was translated and published by FAO (CEEMAT/FAO, 1972); the results have since been widely quoted and considered authoritative, with expressions such as "according to FAO" being used to introduce the figures. Goe and McDowell (1980) provided a table with estimates of the draft capacity of different species drawing "implements" at high or low speeds, based on figures obtained from a wide literature review.

General tables, such as those mentioned above, have been useful at giving people "order of magnitude" estimates of working capacities. Nevertheless from the foregoing sections and chapters, it should be clear that local animals, implements, environments and people vary immensely. Thus concepts of "average draft" or "reasonable work rates" have little meaning in a book such as this. What is "reasonable" in the farming systems of one country or area, might be totally unrealistic in another location. Thus no prescriptive or suggested rates will be presented here, and the "illustrations" of the locally obtained results that have been presented in Tables 10-1 and 10-2 should be treated with appropriate caution. Anyone in need of more specific figures might be best advised to consult local sources of information (farmers or researchers) or those in neighbouring countries (making sure the specific conditions to which any figures refer are clearly understood). Fur-

Photo: Bob Munro

Fig. 10-10: Buffalo walking in mud during experimental trials at CTVM, Edinburgh, on the effects of environmental conditions on draft animal power. The mask (modified bucket) over the mouth allows expired air to be pumped away and analysed. This allows oxygen consumption and carbon dioxide production to be measured, so that the energy used during walking and working can be calculated.

ther sources of more detailed information are mentioned below.

"Reasonable" animal draft has sometimes been expressed as "sustainable" or "maximum" draft force as a proportion of body weight. This overcomes the problem of widely differing weights of animals and draft loads. Thus Hopfen considered normal pulling power to be one tenth (10%) of body weight for most animals, and 15% for horses. CEEMAT (1971) and CEEMAT/FAO (1972) reported that oxen could be expected to produce an average effort of one tenth of body weight on rough ground and 1/8th (12.5%) of body weight when plowing well-worked ground. CEEMAT estimated the sustainable force of donkeys to be 17-25% of body weight. CEEMAT (1971) and CEEMAT/FAO (1972) also suggested there would be a loss of 7.5% draft force per animal as a result of multiple hitching.

Watson (1981) put forward recommendations in line with those of CEEMAT/FAO, of 12% for oxen and 20% for donkeys, less 7.5% per animal if multiple hitching was used. Reh (1982) quoted the CEEMAT/FAO figures but provided a table suggesting significantly lower sustained traction capacities, equivalent to 4% of body weight for oxen and horses and 16% of body weight for donkeys, with losses of 10-28% per animal attributable to multiple hitching. Goe and McDowell put the general figure at 10-14% of body weight for most animals walking at between 0.66 and 1.1 m s^{-1}, with more specific guidelines equivalent to 10-12% body weight for horses, 10-14% for oxen, buffaloes and camels and 10-16% for donkeys. These authors also accepted the CEEMAT figure of 7.5% reduction per animal as a result of multiple hitching.

Pathak (1984) considered that the earlier estimates of 15-20% of ox body weight of Vaugh (1945) had been too optimistic. Pathak advised that draft exceeding 8-10% of ox body weight might put an excessive strain on the animals if it were sustained for several hours.

Subsequently Kebede and Pathak (1987) reported endurance trials in which Ethiopian Zebu oxen had to pull draft loads of 5%, 10%, 15% and 20% of body weight for six hours per day for five days. Power and work output were higher at 10% and 15% than at 20% but Kebede and Pathak concluded that the animals were indeed capable of pulling 20% of their body weight on a sustained basis. Other figures from Ethiopia suggest that normal plowing (carried on for up to four days per week) involved pulling a draft of 17-23% of body weight for six hours per day, (Goe, 1987). Following a programme measuring tillage operations in India, Kemp (1987) suggested that "rule of thumb" approximations of 10% of body weight being applied for tillage tended to overestimate normal workloads actually being applied on a sustained basis.

For illustrative purposes, some examples of draft forces expressed as a percentage of animal or team body weight have been cited in Table 10-2. Some of these were calculated by the authors, but many were computed from overall mean figures contained in the publications. Research reports based on measurements over several hours have reported sustained work output when draft loads of 5-25% of body weight were apparently applied. When measurements were of shorter duration, percentage draft load appears to have been between 10 and 40% of animal body weight. No recommended values will be given here, since to state that an animal of a particular species or breed is capable of pulling a force of 10-15% of its body weight, still begs too much information on how that force is assessed and on hourly, daily or weekly working regimes.

Designers of implements and harnesses have to be aware not only of the normal working forces that animals apply to implements, but also of the high instantaneous forces that can occur in animal-implement combinations. Severe shock loads, that can be 5-10 times greater (and even more) than normal "steady-state" draft, can occur when a moving implement suddenly hits a rock or stump. Animals that are startled, or which panic, may suddenly exert strong forces in unusual, unforeseen directions. Such shock loads can bend weak implements, break unsound harnesses or damage the animal(s) themselves. Designers have to allow significant safety margins of strength if implements and harnesses are to withstand shock loads. Instantaneous forces equivalent to at least 100% of animal or team body weight for oxen may be allowed for; even more if implements are pulled by horses.

10.5 High technology or simple assessment

Before microchips opened up the vast potential of data logging, much research on draft forces was based on readings from spring or hydraulic dynamometers. One of the more comprehensive studies was carried out in the 1960s in several countries in Africa by CEEMAT (Scherrer, 1966) and summarized in CEEMAT, 1971 and CEEMAT/FAO, 1972. Data from studies in many parts of the world were quoted and discussed by Goe and McDowell, 1980, who also provided some guide figures on the draft capabilities of different working animals.

It is interesting that technological progress in instrumentation does not appear to have invalidated these earlier studies, and it must be stressed that useful research can still be carried out using similar techniques. With all the sources of variation discussed in previous sections, it should be clear that in most circumstances the *interpretation* of data is more important than the "accuracy" of its measurement. There have been many cases where researchers developing implements have recorded very precisely the draft of an implement during on-station trials, only to find that the farmers subsequently rejected that implement as being "too heavy". In such cases many months of work might have been saved if the researchers had decided to put aside the dyna-

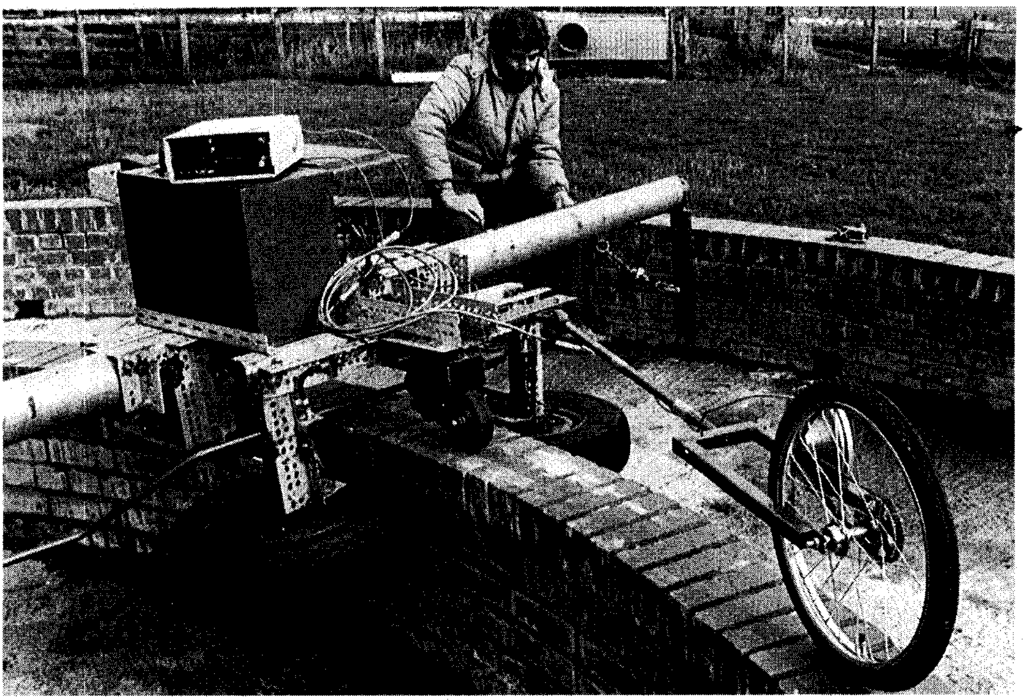


Photo: Bob Munro

Fig. 10-11: Detail of the ergometer used for draft animal research at CTVM, Edinburgh. Work load can be varied through the friction wheels that run round the inner wall, and distance is recorded by the bicycle wheel.

mometer and simply ask some local farmers to test the prototype with their own animals and on their own farms and give their "impressions" of whether the draft was likely to be acceptable or excessive. This should not be taken to imply that there is never any value in precise measurement and replicated experimental designs, for there are times when this is indeed important. However there are also times when people become so bogged down with data collection they cannot see the farmers for the figures!

This chapter has talked about "assessment" in terms of scientific measurements: newtons, metres per second, watts and square-metres-per-hour. Such units are important for permitting the exchange of information between scientists and professional agriculturalists but they mean nothing to the majority of farmers. Yet farmer "assessment" is crucial. All readers who hope that their own work will influence (directly or indirectly, in the long-term or short-term) the design, selection, production, provision or utilization of harnessing and implements must know that actual progress depends ultimately on the farmers and farmers' perceptions. For this reason researchers and development workers should try to incorporate farmer assessment as early as possible in any research-development initiative. Farmers will not use dynamometers, data loggers and calculators in their own assessments, and so it should be possible to develop local performance criteria with minimal equipment. "Farm area cultivated per average team per work day" may not seem scientific, precise or repeatable, but it may be much more relevant than the "knowledge" that an implement has "a mean draft of 857.8N".

For those whose research necessitates very accurate recording of draft force, power and work, computer-based systems of rapid data collection and processing appear to offer great potential. They permit the precise and rapid recording of many of the parameters influencing draft and work rate but it must again be stressed that they are certainly not essential for research in this area. Computer-based systems are not cheap to buy and most importantly their use may well involve a huge investment in professional time and scarce expertise in order that the instruments and equipment are employed effectively and the large quantities of data produced are analysed. Small research-development projects may well decide that such time and money would be more profitably employed if estimates of draft and power are made with simpler instruments so allowing more time to be spent on studying the constraints in the local farming systems. A parallel may be drawn between socio-economic surveys, where "rapid rural appraisals" may yield *relevant* information more quickly and more cheaply than detailed surveys that involve mass data collection and analysis.

Notwithstanding the various cautions given, it is clear that data logging can be an extremely powerful research tool. It would therefore seem appropriate for programmes contemplating *detailed* research studies relating to draft and work rates to contact one or more of the organizations with experience in this very specialized field. This would allow both the technological options and possible research protocols to be discussed. Several of the organizations working in this field would warmly welcome cooperation, and some may have access to resources to allow collaborative research programmes to be undertaken.

10.6 Further sources of information

AFRC-Engineering, UK, has spent much time developing systems for recording draft and work rates. Their system (illustrated in Figs. 10-4 and 10-5) has been described in many articles, including Kemp (1985), O'Neill, Howell, Paice and Kemp (1987), O'Neill and Kemp (1988), Howell and Paice (1988), and Kemp (1989). Field trials involving the use of AFRC-Engineering data loggers have been carried out by ILCA, Ethiopia; CEEMAT, France; CIAE, India and CTVM, Scotland. All these organizations have built up considerable experience in the application of this relatively new technology.

CTVM, Scotland, has developed its own system of data-logging "ergometer" for the measurement of work, draft force, distance travelled and actual working time. This has been employed in trials in Bangladesh, Costa Rica (Fig. 10-9) and Ethiopia. It has also been used in the research of the ACIAR Draught Animal Power Project, Australia. A more complicated system has been developed to allow three additional parameters (body temperature, breathing rate and stepping rate) to be recorded with the work output data. This has proved of value during trials in Nepal (Fig. 10-6; Pearson *et al.*, 1989). At CTVM itself treadmills and circular tracks have been fitted with gas-analysis equipment to allow detailed measurements of energy consumption for working and non-working animals (Fig. 10-10 and 10-11).

The University of Hohenheim in Germany has been collaborating with the ICRISAT Sahelian Centre in Niger in a study of draft animal power capabilities. Work has included the use of a test track and loading sledge to measure both average and maximal power outputs of single and paired oxen, horses and donkeys (Betker and Klaij, 1988).

Organizations in Africa undertaking research relating to the assessment of draft and work include FMDU, Botswana, ILCA and IAR (Nazareth) in Ethiopia, INRA-MIAC Projet Aridoculture in Morocco, the ICRISAT Sahelian Centre and Projet FAO in Niger and AD-PRDP in Zambia. The addresses of these and other organizations working in this field are given in the GATE Animal Traction Directory: Africa (Starkey, 1988).