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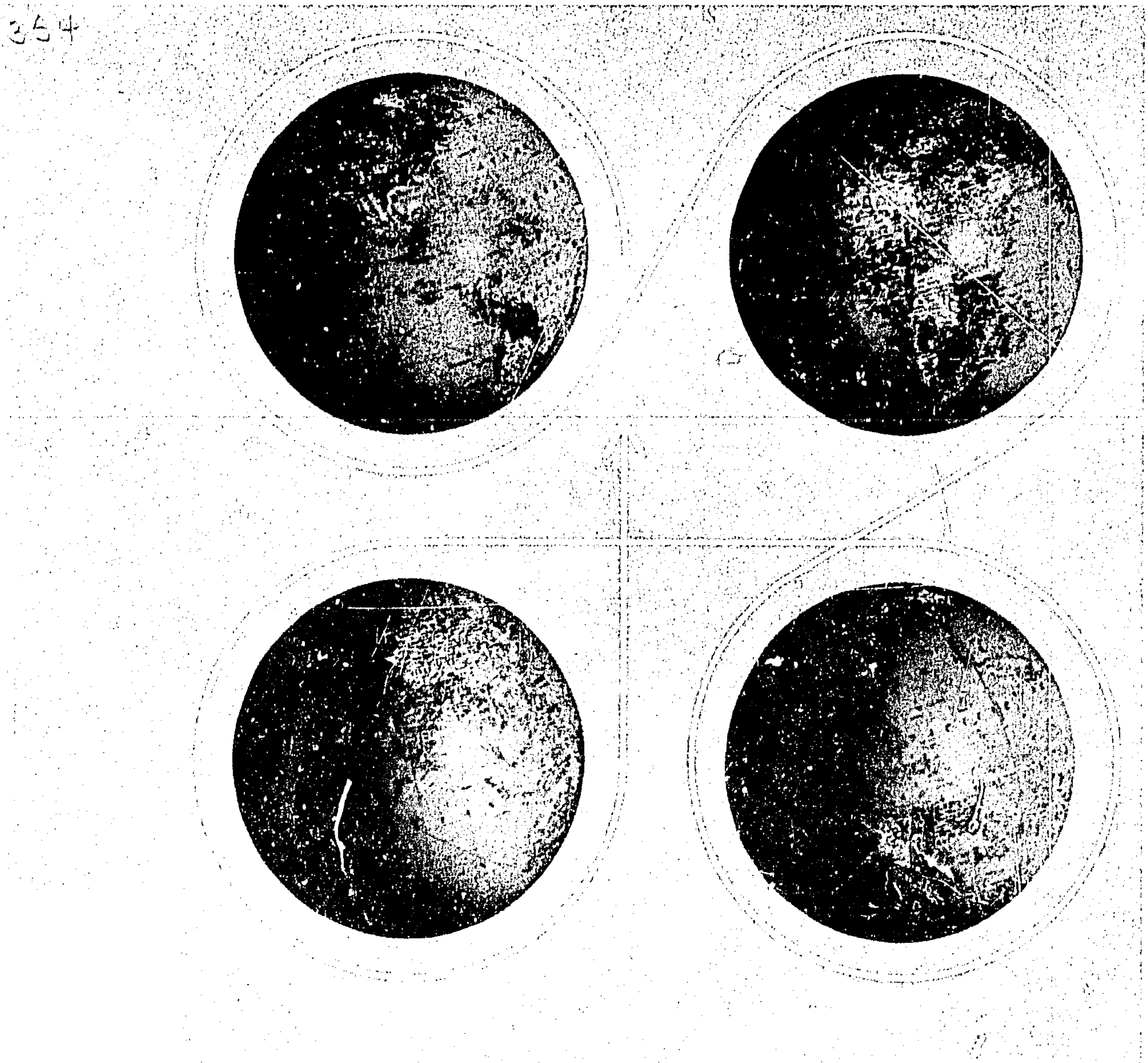

ANIMAL TRACTION: GUIDELINES FOR UTILIZATION

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by

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INTRODUCTION

At present there are conflicting views regarding the use of animal traction in agriculture. Some, hypothesize that increased production can be realized only through the use of mechanization - mainly tractors[1/]. Strong proponents of this hypothesis consider use of animals as a retardation to development. Others see animal power as an intermediate stage to mechanization or as a panacea to achieve agricultural progress in developing countries. Such opinions serve mainly to propound a simple and general solution to a very complex problem as neither mechanization nor animal traction can be singly employed under all conditions. Failure to implement agricultural development programs which integrate both mechanization and animal traction will continue to result in inefficient use of resources to enhance agricultural production. This is especially the case on small farms where capital resources are limited (McDowell and Hildebrand, 1980).

Although agricultural mechanization has increased at a rate of 1 to 1.5% per year in the developing countries (Chantalakhana and Na Phuket, 1979), draft animals continue as a major source of farm power. Hopfen (1969) estimated that nearly 98% of the total agricultural power available in the People's Republic of China, Indonesia, Korea, and the Philippines was derived from animals. Draft animals provided 64% of the effective agricultural power in India in 1966, with 25% coming from human power and only 10% from mechanization (Subrahmanyam and Ryan, 1975). Animal draft cultivation has increased substantially throughout West Africa where 10 to 20 years ago its existence was only minimal (Kline _et_ _al_., 1969; Uzureau, 1974).

Animals utilized throughout the world as a source of traction, include horses, mules, asses, buffalo, cattle, camels, yaks, llamas, alpacas, reindeer, elephants, elk, moose, sheep, goats, and dogs. In addition to furnishing a source of power, these same animals provide milk, fuel, wool, hair, off-spring, and by-products, such as hides, horns, hooves, and meat at the end of their working lives.

The extent to which draft animals are employed in the world might lead one to expect considerable information on guidelines for utilization, but this is not the case. Frequently, governmental organizations are not structured to encompass identification of merits or problems associated with animal traction. The limited research on traction has resulted in data which are often unrepresentative and unsuitable to "actual farm conditions".

[1/] However, studies indicate that substantial increases in yields, timeliness, cropping intensity, and overall returns are not the result of tractor use alone. Rather, increase in production has been due largely to additional inputs, e.g., fertilizers,insecticides, irrigation, improved seed. Ellis (1972); McInerney and Donaldson (1975); Merrill (1975); Binswanger (1978); Duff (1978).

The objective of this paper is to provide a "state of the art" on some of the knowns as well as unknowns about the utilization of animals for traction. The major emphasis is on power for agriculture.

PRINCIPLES OF ANIMAL DRAFT

The efforts of draft animals are often viewed only in terms of work accomplished, e.g., a plowed field, a harrowed rice paddy or goods transported. The basic inanimate physical principles such as friction, force, and speed which influence the process of doing the work are seldom considered; consequently, the power generated by animals is utilized inefficiently and less work is completed. An understanding of the physical principles involved when using animal power is essential for comparing the working ability and efficiency of draft animals between and among species. This chapter defines these principles and evaluates the effects on animal performance.

A. Measuring Power

Although cattle appear to have been first used in 3200 B.C., by the Sumerians for transport, plowing, and threshing of grain (Zeuner, 1963), it was not until the 18th century that the power produced by animals while doing work was actually measured. The unit of measure was termed horsepower by James Watt, inventor of the first practical steam engine. To put his steam engine on the market, Watt needed to determine the number of horses his steam engine could replace. The amount of power was determined by using horses to pull a rope passed over a pulley attached to a weight at the bottom of a deep well. One horse could easily raise a weight of 100 lb (45 kg) while walking at 2.5 mi (4 km) per hr or 220 ft (67.1 m) per min. This accomplished 22,000 ft lb (3041.6 kg m) of work). Watt increased this by 50% to allow for friction in his engine and for good measure, thus establishing 33,000 ft lb (4562.4 kg m) per min or 550 ft lb (76 kg m) per sec as the unit of power or 1 horsepower[2/] (hp). One metric hp is equivalent to .99 English hp or 4516.8 kg m per min. Horsepower is the rate at which work is performed and is calculated using two components; work (force x distance) and time. The amount of hp required to do work is dependent on the rate at which the work is performed. For example, to plow 1 ha of land requires the same amount of work whether the land is plowed in 6 hr with two animals or in 1 hr with six animals. However, the faster the rate of work the more hp needed.

A more accurate term to use when describing the amount of power an animal can produce is tractive hp[3/]. Tractive hp is measured at the point

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[2/] Watt's steam engine was actually capable of producing only two-thirds of 1 hp (Collins and Caine, 1926).

[3/] Referred to as drawbar hp in relation to tractors. Both tractive hp and hp will be used interchangeably in this paper.

where an implement or lever is attached and is the power required for pulling an implement, e.g., plow, cart, or operating a machine, e.g., mill, press. Tractive hp can be calculated by recording the speed of travel (distance x time) and determining the resistance of the load (draft) by means of a dynamometer[4]. The distance traveled in a given amount of time multiplied by the resistance recorded by the dynamometer and divided by a constant equals the tractive horsepower produced.

$$\text{tractive hp} = \frac{\text{draft (kg)} \times \text{speed (km/hr)}}{270}$$

For example, the draft required to pull a 40.6 cm sulky plow through a 15.2 cm deep Sudan grass sod is 227.3 kg. If three horses pulled the plow at a rate of 3.2 km per hr the tractive horsepower would be:

$$\text{tractive hp} = \frac{227.3 \text{ kg} \times 3.2 \text{ km/hr}}{270} = 2.7$$

The power source used, whether animal or machine, must deliver more than the required tractive hp to propel itself in addition to overcoming the draft of the object being pulled or moved (Campbell, 1973). However, due to the difficulty involved in making such a precise measurement, the power exerted by an animal for its own movement is considered to be negligible and is not added to the basic hp required to operate or move an implement (King, 1907; Collins and Caine, 1926; Vaugh, 1944).

B. Draft of Plows

The term "draft" as used in agriculture refers to the force required to pull an object for a given distance. It is sometimes denoted as tractive effort or tractive pull and is one of the major components for calculating tractive horsepower. Implements employed in agriculture require a certain amount of draft to be moved.

The draft of tillage implements, like a plow, is dependent upon such factors as weight of the plow, its shape, sharpness and scouring properties of the plow, angle of draft, character of the soil, skill of the plowman, presence of different attachments, speed of travel, and size of the furrow (Ellis and Rumley, 1911). Examples of variation in draft requirements for various implements drawn from the United States and equatorial Africa are in Table 1 and 2. Horsepower requirements are listed only in Table 1 because the draft of the implements was actually measured by a dynamometer. However, comparison of the draft requirements per area in both tables demonstrates that similar amounts of power are needed for tillage operations in warm and temperate regions.

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[4] A dynamometer is a machine which furnishes tractive resistance at a rate which is constant and proportional to the force that is applied. A measurement is recorded graphically or visually which indicates the draft or force exerted.

Table 1. Draft requirements and speeds of operations for agricultural implements (U.S. data)

	Implement	Depth of tillage (cm)	Draft (kg)	Draft (kg/cm^2)	Speed (km/hr)	hp required
35.6 cm	One bottom moldboard plow	15.3	227	.42	2.4-4.0	2.0-3.4
"	"	13.0	227	.49	"	"
"	"	18.0	191	.29	"	"
"	"	15.3	236	.43	"	"
"	"	10.2	218	.60	"	"
"	Two bottom moldboard plow	13.0	346	.75	"	"
"	"	13.0	627	1.35	"	"
"	"	16.5	293	.49	"	"
"	"	16.5	386	.66	"	"
2.8 m	Disc harrow	—	181	—	3.2-4.0	2.1-2.7
"	"	—	206	—	"	"
"	"	—	250	—	"	"
3.0 m	"	—	268	—	"	"
3.0 m	"	—	296	—	"	"
2.7 m	"	—	257	—	"	"
7.3 m	Smooth harrow	—	336	—	"	"
2.1 m	Cultipacker	—	136	—	"	"
2	Row cultivator	8.9	246	.12	"	"
2	Row cultivator	6.4	136	.11	"	"

Source: Adapted from Collins and Caine (1926).

Table 2. Draft requirements and speeds of operation for agricultural implements in equatorial Africa

Implement	Draft	Speed km/hr
Plow, indigenous	.14-.70 kg/cm^2	1.61 - 2.42
moldboard	.21-1.12 "	2.42 - 4.84
disc	.31-1.00 "	2.42 - 5.65
Disc harrow, single action	.45-1.50 kg/cm	1.61 - 4.03
double action	1.20-2.70 "	1.61 - 4.03
Rotary tiller	.70-3.50 "	.8 - 2.42
Harrow, spike or peg	1.80-2.70 kg/peg	1.61 - 4.84
spring tine	10 - 25 kg/tine	1.61 - 4.84
Roller or puddler	.15-.90 kg/cm	.8 - 4.03
Leveler, float	.30-.70 kg/cm	1.61 - 4.84
Row-crop planter	30 - 70 kg/row	"
Grain drill	6 - 22 "	"
Transplanter	10 - 20 "	.8 - 2.42

Source: Adapted from Kline et al. (1969).

C. Draft of Wheeled Implements

The draft necessary to pull wheeled implements, e.g., wagons, carts, cultivators, is influenced by axle friction, grade, and rolling resistance. Axle friction varies with the load on the wheels, spindle radius, efficiency of lubrication, and materials used in the wearing surfaces, i.e., plain or ball bearings, bronze bushings. The coefficient of axle friction is defined as the number which when multiplied by the total load on the wheels will give the resistance to rotation due to axle friction. The tractive pull required to overcome axle friction varies directly with the radius of the spindle and inversely with the radius of the wheel. Tests conducted by Wooley and Jones (1925) with wagons weighing 1839 kg and having a coefficient of axle resistance of 0.012, showed a draft of 1.9, 1.8, and 1.7 kg per 0.91 MT for front and rear wheel heights of 91.4 and 101.6, 91.4 and 111.8, and 101.6 and 111.8 cm, respectively. Draft increase due to axle friction on implements with properly maintained and lubricated bearings is usually considered negligible; however, the coefficient of axle friction can be as high as 0.072 if lubricant is deficient, bearings are scorched, bushings are worn or absent or seals are broken. Such an increase in the coefficient of axle friction will more than triple the draft in the above tests to 6.3, 5.9, and 5.7, kg.

Grade resistance is independent of wheel size. It depends on the load and slope of the ground. The steepness of a grade is usually expressed as a percentage, or as the measurement of vertical rise per distance of horizontal run (Wooley and Jones, 1925). A 1% grade would be a rise of 1 m per 100 m of run, for example. Grade resistance is equal to the weight pulled multiplied by the percentage of grade and the coefficient of rolling resistance, i.e., the ratio between implement draft and total gross weight moved. The hp required to pull a load at a constant speed will increase as the surface gradient increases. Wooley and Jones (1925) reported that 1 hp was required to pull a load having a draft of 85 kg at a speed of 3.2 km on level ground. To pull a similar load at the same speed up grades of 5 and 10% required 3.3 and 5.7 hp; therefore, the amount of weight pulled should be gauged according to the varying grade and surface of the route selected and the ability of the animal(s) to generate adequate hp.

Rolling resistance, or the resistance caused by the wheels of an implement sinking into the surface over which it is moving or by the surface piling up ahead of the wheels, is dependent upon ground surface, size, width, and type of wheel, i.e., wooden, iron-rimmed, pneumatic, and weight of the load. The coefficient of rolling resistance may range from 0.01 on hard surfaces to more than 0.25 on very wet or sandy ground depending on size and type of wheels and/or tire inflation (FAO, 1972; Campbell, 1973). Data from 629 tests demonstrated that increasing wheel width from 4 to 10.2 cm was more effective in decreasing the draft than was the increase in wheel height from 91.4 to 111.8 cm (Wooley and Jones, 1925). The use of wide wheels of varying heights reduced wagon draft irrespective of ground surface, however, increasing the height or width of the wheel became less effective as the density of the road surface increased. All wagons tested had the greatest draft on muddy roads and plowed ground regardless of wheel height or width, although the increase in draft was found to be less for the higher wide wheels than the others relative to wagon draft on a hard level surface.

Wheel type can also affect the draft of an implement. Use of pneumatic tired carts on both plowed ground and dirt roads will allow for a greater amount of weight to be moved per kg of draft applied compared to iron-rimmed and wooden-wheeled carts on the same surfaces (Sayer, 1934) This ratio widens as the weight pulled on plowed ground is increased, but becomes less pronounced on a dirt road (Table 3).

Collins and Caine (1926) measured the draft required to pull wagons loaded with freight on different road surfaces (Table 4). If tests were carried out on a grade, the load was pulled in both directions in order to prevent the grade from influencing the draft measurement. The results

Table 3. Draft for carts equipped with various type wheels

Type of cart	Ground surface	Weight (kg) Cart	Load	Total	Draft (kg)	Ratio: Draft to weight (kg)
Wooden cart with pneumatic tires	Plowed	364	933	1297	51	1:25
Iron cart with pneumatic tires	"	495	1866	2361	140	1:17
Farm cart with iron rimmed tires	"	373	933	1306	178	1:7
Country cart with wooden wheels	"	252	597	849	127	1:7
Wooden cart with pneumatic tires	Dirt road	364	933	1297	22	1:59
Iron cart with pneumatic tires	"	495	1866	2361	45	1:52
Farm cart with iron rimmed wheels	"	373	933	1306	27	1:48
Country cart with wooden wheels	"	252	597	849	36	1:24

Source: Adapted from Sayer (1934).

show that the initial draft required to start the same load on a variety of surfaces is directly proportional to the draft required to keep that load in motion over those particular surfaces. For instance, the team weighing 1273 kg made initial tractive pulls of 446, 527, 682, and 455 kg for a load of 6500 kg pulled over road surfaces of granite blocks, concrete, asphalt, and brick. The tractive pulls required to keep the load in motion were relative to the initial draft required to start the load, decreasing to 39, 46, 182, and 48 kg. Such trials demonstrate not only the influence of ground surface on implement draft, but also, the ability of draft animals to generate power over extreme ranges within very short periods of time.

D. Line of Draft

The true line of draft of an implement, such as a plow, wagon or cultivator, is the point from which the implement can be pulled with the least amount of force. The line of hitch or pull by the animal(s)

Table 4. Draft required to start and keep in motion wheeled cart loads over various road surfaces using a single animal or team

Animal weight (kg)	No. horses	Total weight wagon and load (kg)	Granite block		Concrete		Asphalt		Brick	
			A	B	A	B	A	B	A	B
784	1	3046	432	14	—	—	546	55	—	—
727	1	2182	364	27	441	9	546	36	—	—
1455	2	6155	546	65	446	42	591	153	—	—
1273	"	6500	446	39	527	46	682	182	455	48
1546	"	7409	736	91	—	—	818	173	—	—
1591	"	6773	1091	77	—	—	—	143	750	73
1505	"	4675	446	46	—	—	455	107	—	105
1414	"	3146	98	27	—	—	223	72	—	—

a/A - To initially move load.

B - To pull load once in motion.

Source: Adapted from Collins and Caine (1926).

should be as close to the true line of draft of the implement as possible. Hitching a plow off the true line of draft can cause additional friction resulting in a 10% increase in the tractive pull (Horse and Mule Association of America, 1946).

The size of the angle between the line of hitch and the ground will also influence the draft of an implement. Using both short and long beam plows it was shown that as the angle between the plow and the animals decreased, draft decreased. A single moldboard plow with a short steel beam had a draft of 145 kg vs 131.5 kg for a similar plow with a long wooden beam. The more acute angle also reduced the downward force required to keep the plowshare at the proper working depth, i.e., the downward force on the short beam plow was 86 kg compared to 49 kg for the long beam plow (Ramiah _et al._, 1956).

Keeping the line of hitch as nearly parallel to the ground as possible will reduce the force required of both the animal(s) pulling the implement and the operator. The force can be minimized not only by using a long beam, but also, by employing a harness having a collar or breaststrap which allows for adjustment of the traces for animals of various sizes and different implements. Unfortunately, cost and tradition often make the use of these methods the exception rather than the rule.

DRAFT CAPACITY OF ANIMALS

This section examines horsepower developed by draft animals during maximum pulling trials and under field conditions, and the effects of body size on working efficiency. Draft performances of animals in temperate and tropical areas have been largely separated because of different environmental, nutritional, and prevailing management factors. It is recognized, however, that there are similarities among draft animal performance in both areas and therefore, comparisons between the two groups have been made where appropriate.

A. Power Produced at Maximum Effort

Collins and Caine (1926) used a dynamometer to measure the maximum hp developed by teams of draft horses in pulling contests. The teams were required to pull the dynamometer a distance of 8.4 m without stopping. Horsepower was recorded for the team that set the world's record that year (Table 5). The amounts of hp developed for trials three and five are lower than the others because the team was not hurried during the pulls. The contest was judged on maximum pull rather than maximum hp produced. This study deomonstrates that the amount of hp developed is not based on the amount of weight pulled, but on time. In trial three the team took 11 sec to pull a load of 1361 kg and developed 13.8 hp. If the time to cover the 8.4 m had been 5 sec, hp developed would have been 30.5. In trial two, the team managed to generate 30 hp by pulling a lighter load the set distance at a much faster rate than those recorded in trials three through six.

Korzenev (1955) conducted performance tests on a dirt track using Vladimir draft stallions. One animal was able to pull a load of 16,413 kg

Table 5. Record of pulls made by the winning heavyweight team

Trial no.	Distance (m)	Time (sec)	Tractive pull (kg)	hp
1	8.4	4.0	907	25.4
2	"	4.2	1134	30.2
3	"	11.0	1361	13.8
4	"	8.0	1452	20.3
5	"	11.0	1542	15.7
6	"	9.8	1554	17.8

Source: Collins and Caine (1926).

for 450 m in 4.5 min. The same animal pulled 900 kg over 2000 m in 5.5 min during a trotting test. Since the draft of the loads was not given, hp could not be calculated.

Hesse (1956) compared the working ability of small horses with large horses and cows. Data from maximum pulling tests conducted for 2 and 4 hr periods showed that Fjord and Hafling ponies could pull approximately 65.5% of the weight pulled by Rhenish-German grade horses and 116% of that by Red Angeln, Black Pied Lowland, German Red, and Yellow Franconian cows. Corresponding figures for Iceland ponies were 43.6% and 77.4% and for Shetland ponies 21.8% and 38.7%. Over a distance of 40 m the record loads pulled by a Rhenish horse and Fjord pony were 494 and 396 kg, respectively.

In other trials with horses (Ishizaki et al., 1954), the mean draft resistance did not exceed approximately 10% body weight of the animal; hence, there was no significant correlation between speed and body weight. However, if the horses were subjected to heavy work such as plowing paddy fields, the correlation was significant. Although maximum draft developed by the horses was roughly proportional to their body weight, light horses were able to bear heavier packs than expected from projected calculations based on 10% of body weight. Draft performance tests carried out by Prawochenski and Piotraszewski (1955) gave similar results. Trials carried out over a two year period with 1420 horses showed a small, but significant, negative correlation between maximum load a horse could pull (expressed as a percentage of its live weight) and its live weight. This indicates that the smaller the horse, the greater the maximum weight it can pull in relation to its body weight. Light horses (562 kg) could pull about 77% their body weight, whereas, heavy horses (mares 700 kg and stallions 770 kg) pulled loads equivalent to 69.6% of their body weight.

Kleisch and Neuhaus (1948) found that two mature German lowland oxen, weighing 1629 kg, were able to produce a maximum tractive effort of 5300 kg. These same oxen were able to pull a loaded wagon weighing 2850 kg for a distance of 700 m in 6.5 min. In other trials, a pair of oxen weighing 1502 kg were able to pull 8550 kg or more than 5.5 times their body weight. Another pair pulled a wagon with a load of 2500 kg or 4.5 times their body weight for a distance of 1000 m in 12.2 min.

Haring _et al_. (1956) recorded that oxen from the highlands of Hessen, Germany, were able to pull loads much faster than lowland cattle and their superiority became more pronounced as the loads increased. Hopfen (1969) reported that in 2 and 4 hr of work maximum pulls made by highland cows were 160 to 170 and 140 to 150 kg, respectively. For the same time periods lowland cows recorded maximum pulls of 140 to 150 and 120 kg.

Other performance tests carried out in temperate areas, such as Ishizaki and Honzawa (1949); Fischer (1950); Ivanov (1950, 1952); Kruger and Seefeldt (1955); Tolaine and Roston (1957), substantiate the studies reviewed. The draft and hp developed during maximum pulling trials should not be considered representative of the power which animals generate when used on a daily basis for work (Collins and Caine, 1926; Brody, 1945). Pulling trials demonstrate the reserve or "overload" strength which is utilized when initially starting a mill or press or when encountering rocks, roots or stumps when plowing or pulling a load (Wooley and Jones, 1925; FAO, 1972). Such exertion of extra effort cannot be maintained for long periods of time without causing physical damage to an animal and thereby reducing its usefulness for work.

B. Work Efficiency of Animals

The work efficiency of animals is defined as the ratio of energy recovered in the work accomplished to the total energy expended as determined by the rate of oxygen consumption. For example, if a horse working at the rate of 1 hp (270,000 kg m or 633 kcal per hr) consumed oxygen equivalent to 3165 kcal, the energetic efficiency of the work is 633/3165 X 100 = 20%. The energetic efficiency of muscular work can be divided into 3 categories: gross, net, and absolute (Brody, 1945). These are defined:

$$\text{Gross efficiency} = \frac{\text{work accomplished}}{\text{energy expended}}$$

$$\text{Net efficiency} = \frac{\text{work accomplished}}{\text{energy expended above that at rest}}$$

$$\text{Absolute efficiency} = \frac{\text{work accomplished}}{\text{energy expended above that of walking without load}}$$

The maximum energetic efficiency measured for draft horses was nearly 25% for gross, 28% for net and 35% of absolute[5/]. Gross efficiency is the

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[5/] Hill (1927) calculated the maximum theoretic efficiency of a contracting muscle as approximately 40%. According to Brody (1945), this is analogous to absolute efficiency. This would allow for 60% of the remaining most applicable to this discussion because it includes not only the energy of actual work accomplished, but also, the overhead energy of walking and resting. Energetic efficiency of muscular work is measured in terms of metabolites oxidized in the body as determined by oxygen consumption and not in terms of energy converted from feed to body metabolites (Brody, 1945). The latter involves considerable waste and will reduce overall efficiency. If the energy cost of feed conversion is included, the overall efficiency of equines will be reduced to 10 to 15% and bovines to 9 to 10% (Brody, 1945; FAO, 1972).

Experimental findings reported in the previous section showed that in proportion to body weight, small animals could pull or carry greater loads than large animals; yet, draft capabilities of animals are largely dependent on body weight, i.e., two animals, each one having the muscular power to utilize its entire weight, the heavier one will exert the larger draft (King, 1907). To compare the energetic efficiency between different size animals requires consideration of the total work accomplished. In terms of hp produced, small animals are able to develop a greater gross efficiency than large animals since decreasing the weight of an animal increases the value of the ratio $\frac{\text{hp}}{\text{weight of animal}}$, and therefore, increases the efficiency (Proctor _et al._, 1934). This merely demonstrates that for a large animal to perform work as efficient as a small animal, it must do twice the work of the latter. The work done must vary in direct proportion with animal size for efficiency to remain constant[6]. Proctor _et al._ (1934) stated that "for given rates of work done the energetic efficiency of the work decreases with increasing size of the (animal), but differences in efficiency between large and small (animals) decline with increasing amount of work accomplished." Brody and Trowbridge (1937) demonstrated that maximum energetic efficiency is independent of size of even species of animal. Small and large animals all reached approximately the same maximum gross efficiency level of 24% while working. Experiments have shown that the fewer the working hours per day, the lower the all day efficiency.

The energetic efficiency of animals will increase as draft and speed increase until an optimum rate of work is reached. Draft horses, weighing 680 to 862 kg, appear most efficient when working at a rate of 1.0 horsepower (King, 1907; Collins and Caine, 1926). A horse could

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energy to be expended partly for overcoming external resistance (wind, contact of feet with ground, etc.) and incidental motions associated with work. However, most of the energy is expended for overcoming the internal resistance of body colloids. Although this resistance is energetically wasteful, it protects the animal from physical injury by limiting the forces which can be exerted on the joints, bones, tendons, etc. (Hill, 1927).

[6] When animals are resting, a large animal consumes more feed than a small one, so that while large and small animals are able to work with equal efficiency, the feed cost of upkeep of a large animal is greater.

generate a tractive effort equivalent to 10% its body weight walking at a speed of 3.5 to 4 km per hr for 32 km per day over a period of two years, without showing signs of physical stress. Other tests showed that draft horses of similar weights had the highest energetic efficiency when working at a rate of 1.0 hp while exerting a tractive pull equal to 15% of body weight at a speed of 2.4 km per hr (Brody and Trowbridge, 1937). Water buffalo have attained a maximum gross efficiency of 23.5% when producing tractive efforts of 80 to 100 kg. Net efficiency was 28.5% at hp ranging from 0.8 to 1.2 (Johnson, 1964). A pair of Hariana bullocks, weighing 813 kg, were most efficient when drawing loads with a draft of 60 kg at a speed of 3.8 km per hr or working at a rate of 0.8 hp (Devaddatam and Maurya, 1978). These tests indicate the importance of employing animals at a rate which will allow for maximum work to be accomplished per day. In general, animals have the highest energetic efficiency when working at a given hp at a slow speed pulling a heavy load than at a high speed pulling a light load (Brody, 1945)[7/].

1. Efficiency of Animals in Teams

Animals hitched as a team incur a loss of energetic efficiency which is relative to the tractive effort of a single animal (Marks',1951; FAO, 1972). This loss amounts to 7.5% for two, 15% for three, 22% for four, 30% for five, and 37% for six animals. For example, if one animal weighing 450 kg was able to generate a tractive effort equal to 10% its weight (45 kg), a pair of the same strength could be expected to develop a total tractive effort of 83 kg. Total tractive pull increases as more animals are hitched together, but tractive pull per animal decreases. Trials conducted in West Africa (FAO, 1972) showed that a pair of 1/2 Brahma oxen generated approximately twice the tractive pull per animal as compared to the two and three pairs of Madagascar Zebu bullocks (Table 6).

Table 6. Tractive effort produced by pairs of animals

Type of animals	Pair(s)	Weight (kg)	Average effort (kg)	Maximum effort (kg)	Tractive pull per animal (kg)	
					Average	Maximum
1/2 Brahma oxen	1	1060	147	310	74	155
Madagascar Zebu bullocks	2	1300	160	400	40	100
"	3	1945	200	435	33	73

Source: Adapted from FAO (1972).

[7/] Total energy cost for doing work is less at a higher speed due to the saving of maintenance expense resulting from the reduction in time required to complete the job. (Provided that the increased time required for recuperation following work at a higher speed is not included in the expense) (Brody, 1945).

Plowing in the Northern Great Plains and the Pacific Northwest in the U.S. was carried out with two and three bottom 35.6 cm and 40.6 cm moldboard plows. The numbers of horses ranged from four to twelve and amount of land plowed in a 10 hr day ranged from 2 to 3.6 ha (Table 7). A five horse team was most commonly used when plowing with the 2-bottom 35.6 cm plow. The addition of a sixth horse did not result in a greater number of hectares plowed per day, i.e., five and six horse teams pulling 2-bottom 35.6 cm plows were able to plow 2.1 ha in a 10 hr day. Similar results were obtained for harrowing and cultivating (Table 8). Hectarage harrowed by teams of six horses was only 4% greater than for teams of four horses when pulling harrows 6.1 m in width. The difference in hectares harrowed between four and five horse teams pulling a harrow 7.3 m in width was only 8%. In both instances employing additional horses accomplished only slightly more work due to the loss in efficiency which occurs as the number of animals hitched together is increased.

Table 7. Rates of plowing, U.S.

Region	Implement[a]	Number Reports	Number Horses	Ha/10 hr
Northern Great Plains	2-bottom 35.6 cm moldboard	64	4	2.0
	"	219	5	2.1
	"	132	6	2.1
	3-bottom 35.6 cm moldboard plow	45	8	3.4
Pacific Northwest	2-bottom 35.6 cm moldboard plow	46	6	2.1
	2-bottom 35.6 cm moldboard plow	32	8	2.0
	2-bottom 40.6 cm moldboard plow	42	"	2.6
	3-bottom 35.6 cm moldboard plow	42	"	2.9
	"	48	9	3.4
	"	41	10	3.4
	"	13	12	3.6
	3-bottom 40.6 cm moldboard plow	34	12	3.6

[a] The size of implement is the working width and in some cases represents two or more implements in a combination hitch.

Source: Adapted from Washburn and Merrick (1936).

Table 8. Rates of harrowing and cultivating, Northern Great Plains, U.S.

		Number		
Operation	Kind and size of implement[a]	Reports	Horses	Ha/10 hr
Harrowing	4.6 m spike-tooth harrow	71	4	12.2
	4.9 m "	36	"	13.3
	5.5 m "	12	"	14.0
	6.1 m "	176	"	16.1
	"	22	5	17.6
	"	45	6	16.8
	6.7 m "	21	4	18.2
	"	12	5	18.7
	"	5	6	22.6
	7.3 m "	77	4	18.0
	"	23	5	19.5
	"	36	6	20.6
	7.6 m "	7	4	16.4
	"	6	5	21.7
	"	17	6	22.6
	7.9 m "	67	4	19.1
	"	38	5	19.6
	"	38	6	22.6
	8.5 m "	8	4	17.0
	2.7 m spring-tooth harrow	4	4	7.6
	"	2	6	8.0
	3.1 m "	3	4	6.3
	3.7 m "	3	4	9.0
	"	5	6	9.6
Cultivating	2.4 m duckfoot cultivator	7	6	5.7
	"	10	4	6.6
	"	7	6	6.1
	2.7 m "	20	6	6.3
	3.1 m "	9	6	7.3

[a] IBID. (Table 7).

Source: Adapted from Washburn and Merrick (1936).

Type of work and rate at which it is performed will dictate the number of animals needed. Certain operations, e.g., plowing very wet soil or pulling heavy loads at a fast speed, require substantial power to overcome implement draft. Even though tractive effort per animal is reduced as the size or number of teams is increased, the addition of animals may be necessary in order to provide adequate power to accomplish the work. A problem arises, however, when the animals being hitched together are not of the same size. Smaller animals suffer especially, since they are not only exerting an effort to pull the implement, but they are "pulling against" larger animals, which may be either walking at a faster pace and/or twisting the yoke or harness due to their greater height. The use of poorly designed or fitting yokes or harness will add to efficiency loss as team size is increased.

While data in Tables 7 and 8 are useful for determining approximate work capacities of draft animals, it should be emphasized that the values given represent cultivation trials carried out under different conditions. Many factors are involved which can cause the results to vary, e.g., weight of the animals used, driver's experience, surface and grade of the road or land, implement draft, load or object being moved, cohesive properties and other physical characteristics of the soil being tilled, design and fit of the collar or yoke, level of feeding, health, and training of the animal. These factors either individually or collectively will have an effect on the working performance of the animals being employed and, therefore, on amount of land which can be cultivated.

ANIMAL TRACTION IN WARM CLIMATES

Animals used for power in the warm climate regions, principally between 30°N and 30°S latitude, often undergo more stresses than in temperate areas. The prevalence of disease, thermal stress, high variability in available feed, and poorly designed harness, yokes and/or implements often contribute to inefficient use of animal power. Some tests of draft capabilities of animals for maximum output and working potential in warm climates are discussed.

A. Horse

Horses are relied upon as pack animals and for transport in the mountainous areas of Central and South America and Asia. They are used for carting goods in Western and Northern Africa and South and Southeast Asia because they are capable of pulling loads faster than cattle or buffalo. Often horses can perform field work at a faster rate than cattle or buffalo, excluding the harrowing operation of lowland rice (Table 9). However, their use is hindered due to higher purchase price, greater susceptibility to injuries and sores resulting from poor fitting collars and yokes, and stricter nutritional requirements than cattle or buffalo (van Leeuwen, 1952).

Horses in Senegal are employed for draft more than oxen because of their abundance. They are used for pulling light carts or seeders. Guary (1962) reported that one horse was capable of pulling a seeder weighing

Table 9. Number of hr required by four species to prepare 1 ha of land[a]

Type of task	Horses	Bullocks	Cows	Buffalo
1st plowing, lowland rice field	30.8	35.5	36.1	38.8 (3)
1st harrowing, lowland rice field	34.9	23.1	28.5	29.6
1st plowing, upland dry ground	34.9	40.9	49.5	47.9
1st harrowing, upland dry ground	21.9	28.2	—	29.0

[a] Based on two animals per team or yoke unless otherwise indicated.

Source: Adapted from van Leeuwen (1952).

30 to 50 kg at a rate of 3.6 km per hr. Monnier (1965) stated that horses weighing 250 to 350 kg were able to generate a tractive effort of 35 kg. Data gathered by FAO (1972) showed that a horse weighing 265 kg was able to make a maximum tractive pull of 550 kg at a speed of 4.8 km per hr. This is equivalent to 9.7 hp or a pull of twice the horses's weight. After seven tests, the mean tractive pull of the same horse was 425 kg at a speed of 4.7 km per hr, thus, generating a hp of 7.4. Tolaine and Roston (1957) reported the average tractive efforts of draft horses in Brazil as 10 to 12% of their body weight over a period of 10 hr, which is similar to values for temperate areas: King, 1907; Collins and Caine, 1926.

B. Ass and Mule

Both asses and mules are employed for packing, riding, and draft in Asia, Northern Africa, and Central and South America. The largest populations occur in Ethiopia, Mexico, Brazil, Turkey, Afghanistan, and Morocco (FAO, 1978). The amount of weight carried by an ass or mule will depend on the size of the animal, type of pack saddle used, and route traveled. Government asses in Sudan, ranging in height from 90 to 110 cm at the withers, are limited by government regulations to pack loads of 45 to 67 kg, although privately owned asses often carry loads of 91 to 135 kg. Riding asses are approximately 100 to 120 cm in height at the withers. These animals are utilized for transporting lighter loads at a faster pace (Cole and Ronning, 1974). Pack mules are sure-footed animals which are preferred over horses when traveling over rugged terrain due to their calmer disposition. Mature mules can travel 40 km per day carrying 112 kg for up to 30 days (Daly, 1901; Boniface, 1903).

Asses weighing 200 to 300 kg and mules of 350 to 550 kg were able to pull loads with approximate drafts of 30 to 40 and 50 to 60 kg, respectively (Hopfen, 1969). The hp generated from such pulls was 0.4 for asses and 0.7 for mules. Mules and asses, like horses, are limited in the tractive pull they can exert relative to their body weight. Asses in Senegal were unable to develop a tractive effort greater than 25 kg due to their light weight (Monnier, 1965). FAO (1972) reported that an ass weighing 160 kg could produce an average tractive pull of 46 kg for 3 to 3.5 hr a day for 10 out of 14 days. One ass weighing 155 kg was able to develop a maximum tractive pull of 355 kg at a speed of 4.5 km per hr or nearly 6 hp. A pair of asses weighing 310 kg were able to develop a maximum tractive pull of 480 kg or 8 hp. It was found during the trials that attempting to work an ass for more than 3.5 or 4 hr was most difficult, no matter how long the period of rest. In general, an ass is able to pull 16 to 20% its weight at a speed of 2.5 to 2.8 km per hr for 3 to 3.5 hr.

C. Buffalo

Swamp buffalo are employed extensively for draft in South and Southeast Asia for rice production. They are generally considered stronger, although slower than cattle (Table 9). Their flexible foot joints (fetlock and pastern) and larger hooves allow them to perform better than cattle in heavy wet soils (Cockrill, 1974). Both males and females are commonly utilized for draft. Milk production of the Swamp buffalo is low compared to that of the River buffalo which is used primarily in commercial dairying operations in India, Pakistan, Egypt, and Eastern Europe.

Buffalo are commonly trained at 3 to 4 years of age, although depending on the country and/or region, training may begin as early as 2 years or as late as 8. Similarly, the age at which work animals are castrated ranges from as early as 9 months in Laos, to 5 years in India, where the operation is delayed until the animals' offspring can be judged for qualities of type and draft. Castration may not be practiced in some areas due to religious beliefs. (FAO, 1977).

Swamp buffalo in Thailand work an average of 5 hr per day for land preparation with the number of work days per year ranging from 66 to 146 (Cockrill, 1974). Rates of plowing for buffalo in different zones in Thailand vary (Table 10). The average working life of a buffalo ranges from 10 to 20 years (Cockrill, 1974; FAO, 1977; Chantalakhana, and Na Phuket, 1979).

Buffalo are capable of a large tractive pull on a dead weight, but are slow for road traction. Oxen are sometimes yoked with buffalo for moving heavy loads on roads (FAO, 1977). Those regularly used on roads having hard surfaces are commonly shod to prevent wearing of the hooves. Shoes referred to in Java as "trompahs", are constructed from old rubber tires, while in Taiwan and India, shoes are made of tightly woven straw pads and thin iron plates, respectively (Cockrill, 1968).

Buffalo are used to transport goods in Bulgaria and Yugoslavia and for hauling water casks in Turkey. They also supply power for the operation of grain mills. In Burma, they are employed to drag teak logs from the edge of the forests to the nearest point at which they can be loaded for carting to mill, railhead, rafting place or to streams for floating

Table 10. Rates of plowing in Thailand with buffalo

Region	Hr worked per day	Ha/day/buffalo	Total days per year
Tha Pra-Udorn-Ubol	4.8	.08	138.3
Central Plains Southeast	4.9	.11	146.1
Korat	5.1	.08	139.6
North	5.2	.11	66.1

Source: Cockrill (1974).

out during the rainy season (Cockrill, 1974). Buffalo are preferred to cattle for threshing of rice where trampling is used, and they perform such tasks as operating a water lift for irrigation better than cattle (McDowell, 1972).

In China a fully grown castrate of the "round barrel" type of Kiangsu province plowed 0.25 to 0.33 ha of irrigated land in a working day of 8 to 10 hr, broken by five intervals of rest. In Hupeh province, a Wuchu castrate did all the work required on 2.3 ha of cultivated land. Liu (1978; cited by Chantalakhana and Ha Phuket, 1979) reported that Swamp and River buffalo in Kwangsi province, could produce maximum tractive efforts of 16 to 16.5% of their body weight. Plowing trials using Swamp buffalo and F_1 Murrah crosses demonstrated that the crossbred could prepare 0.02 ha of land more per hr than could the Swamp buffalo. A Tangyang castrate may draw a load of 100 to 500 kg or pack 100 to 150 kg over a distance of 25 km in a day (Epstein, 1969; FAO, 1977).

A good pair of intact males in Pakistan was able to haul a 2 MT load over 25 to 32 km in a working day. In East Java, similar males pulled loads of up to 1.5 MT on two-wheeled drays weighing about 500 kg at a little over 3 km per hr carrying produce to markets (Cockrill, 1974).

Under normal working conditions, a mature buffalo can develop a tractive effort of 10 to 14% its weight. Stout (1966) reported that a buffalo weighing 452 kg produced a tractive pull of 55 kg at a speed of 3.6 km per hr, generating 0.73 hp. This is similar to that of 0.75 hp reported by Hopfen (1969). Draft produced within the above ranges will vary, depending on type of harness or yoke employed.

Garner (1957) conducted maximum load and endurance tests with buffalo in Thailand using traditional and improved harness. Maximum tractive pulls were carried out using a stone boat constructed of wood with 5 x 15.2 cm runners. The stone boat was loaded until an animal could no longer move it forward. The largest loads (including the stone boat) were 639 and 705 kg which were pulled with a breast strap and collar harness. For the maximum endurance tests a load with a draft of 341 kg was pulled for a pre-measured distance of 503 m. Using three different types of harness: yoke, collar, and breast strap, the loads were pulled the set distance in 31.5, 21, and 18.5 min, respectively. The hp developed for each pull was 0.53 for the yoke, 0.79 for the collar, and 0.89 for the breast strap. There are several advantages to using a collar or breast strap such as easier breathing, less chance of yoke galls, better control over depth of plowing, and the line of draft is lower to the ground. However, there are also problems with the two improved types of harness; durability and cost of the materials from which the collar and breast strap are constructed. Both burlap and leather are susceptible to rotting when frequently wet unless properly treated periodically with a preservative. This will require additional labor by the farmer which he may not feel is warranted enough to carry out on a scheduled basis. The initial and repair cost of other components making up the harness, i.e., the hooks, rings, and chains, may be financially prohibitive to the farmer. While the chains may be stronger and more durable than locally available rope, there exists a greater chance of injury to the buffalo if it becomes frightened or excited and runs from its driver. Although the feasibility of introducing such technology is questionable, these trials effectively demonstrated that more efficient utilization of animal power could be achieved with properly fitting harness.

D. Oxen[8/]

Information on draft generated by oxen and bulls in warm climates can be divided into two categories; tractive effort produced and amount of work accomplished while powering different implements or machines for 3 to 10 hr per day, and maximum draft generated for short lengths of time.

1. Working Draft

The speed of travel and size of load which mature bulls or oxen can maintain is highly dependent on mature body weight, type of yoke, terrain, ground surface, temperature, and type of cart or wagon used. Joshi and Phillips (1953) and Joshi et al. (1957) reported that normal speed of travel on flat or nearly level ground was 3.2 to 4.0 km per hr over a period of 8 to 10 hr. Loads transported by bulls and oxen weighing more than 350 kg may vary from 360 to 1360 kg and 680 to 1800 kg with carts and wagons having iron-rimmed wheels and pneumatic tires. Estimates of the working capacity of different types and breeds of cattle commonly employed for draft in Africa and South and East Asia are in Appendices A and B.

In Zaire, the use of four-wheeled rubber tired wagons allowed one animal to move a load nearly three times that pulled on a cart with two metal wheels due to less rolling resistance (Table 11) (Mathieu, 1959).

Gaury (1962) stated that a pair of well fed oxen could maintain a load with a draft of 90 to 100 kg at a speed of 2.2 km per hr (0.7 to

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[8/] Oxen as used here applies to castrated male cattle.

Table 11. Work performed by oxen in Zaire

Number of animals	Implement pulled	Km or ha covered
1	Cart with two large metal wheels	2 km seven times with a load of 450 kg
2	Wagon, four rubber tires	14 km with a load of 2500 kg
2-4	Double plow (105 kg)	3.2-6.0 ha depending upon the terrain
1	Cultivator	12.0 ha
2	Hay cutter	1.1 to 2.0 ha of prairie and 0.5 to 1.0 ha of heavy grass
2	Rake	2.0 to 3.0 ha
2	Seeder	1.5 ha

Source: Mathieu (1959).

0.8 hp) or pull a plow weighing 15 kg at a depth of 12 cm with a draft of 50 kg. Gaury reported the minimum tractive pull of two healthy oxen in Mali as 80 kg, which is the amount of draft often necessary for basic land preparation.

In Senegal it was determined that a minimum of 80 to 100 kg of draft was required for performing various tillage operations; plowing, seeding, weeding, and harvesting (Monnier, 1965; Nourrissat, 1965). Mature N'Dama and N'Dama X Zebu oxen (350 to 450 kg) are commonly used for draft. They are able to develop an average tractive pull of 35 to 45 kg, equivalent to 10% of body weight. However, some operations require tractive efforts up to 220 kg if the soils are high in clay, therefore, making it sometimes necessary to employ teams of up to three pairs of oxen (Nourrissat, 1965).

In India, two oxen walking at a rate of 4 km per hr while powering a Persian wheel with a draft of 59 kg, generated 0.87 hp (I.A.R.C., 1966). When plowing, a pair of oxen developed from 0.3 to 1.9 hp walking at speeds of 2.7 to 2.8 km per hr and slowing down to 1.9 km per hr at the end of the day.

Matthews and Pullen (1975) found that N'Dama bulls, a small breed, Bos taurus type, adapted quickly to the wet paddy soil. Based on a 5 hr working period, a pair of bulls could plow, harrow, and level 0.15 to 0.22, 0.33 to 0.49, and 0.26 to 0.5 ha, respectively. While cattle are not as suited to paddy cultivation as water buffalo, these trials, like those of van Leeuwen (1952) previously mentioned, illustrate the possibility of using oxen for rice production provided good water control can be maintained.

2. Maximum Draft

At the Indian Veterinarian Research Institute, Izatnagar, 24 Hariana bullocks weighing an average 460 kg, were tested for maximum pulling performance (Mukherjee et al., 1961). The loads were pulled on two-wheeled carts on a smooth paved road over a distance of approximately 0.5 km for a 6 hr period. Maximum loads ranged from 310 to 540% of body weight. While no dynamometer was used to determine the draft generated by the oxen to start the loads and keep them moving, it is reasonable to assume that the ratio of the tractive efforts required are similar to those recorded by Collins and Caine (1926) discussed earlier.

Other tests in India employing different types of yokes showed that pairs of oxen weighing 709 kg pulled loads of 360 kg or 51% of their body weight. Single animals (372 kg) were able to exert maximum tractive efforts of 66% of their weight. Yokes which restircted side movement were undesirable (Vaugh, 1944). Trials conducted by Swamy Rao (1964) and FAO (1972), clearly demonstrated that an increase in pulling power could be obtained with improved yokes and harness (Table 12). A corresponding increase in power was reported by Ali (1977) who stated that the desi (locally made) yoke commonly used by small farmers produced about 22% less power than the improved Nagpure yoke and 60% less than the Allahabad harness.

Although increased efficiency and tractive effort can be achieved by using improved harness or yokes, the main obstacle of "farmer acceptance" has yet to be overcome on a broad basis. Prohibitive factors to such acceptance include replacement cost, reduced versatility, increased maintenance, and lack of knowledge regarding animal efficiency and comfort.

The average tractive pull of oxen on regularly worked agricultural land is approximately 14% of body weight, whereas on land which has been poorly cleared and/or tilled infrequently, the tractive pull is reduced to 10% (FAO, 1972; Nourrissat, 1965; Renaut, 1966; Sargent, 1977). Monnier(1965) suggested that the draft capability of oxen could be increased from 10% to 20% with proper feeding. Although such an increase would offer substantial benefits in tractive effort, it is doubtful that with improved feeding alone a 10% increase over normal draft production is feasible, as extensive tests with well fed draft horses in temperate areas demonstrated that the animals were only able to develop a constant draft of 10% of their body weight during a 10 hr working day.

Reports of oxen developing a draft of 20% of their body weight under average working conditions are few. Values of up to 24% were reported by Swamy Rao (1964; cited by Devadattam and Maurya, 1978), however, these were obtained using improved harness. The Indian Council of Agricultural Research (1966) reported that pairs of oxen, weighing 727 to 909 kg, pulled moldboard plows having a draft of 145 to 182 kg (20% of their body weight) on a daily basis for up to 1.2 months without any adverse effect on their health. While harness type was not described, it appears unlikely that two animals could exert such a large tractive effort under field

Table 12. Maximum instantaneous efforts by cattle

No. and type of animals	Number of tests	Body weight (kg)	Average instantaneous effort (kg)	Speed (km/h)	Maximum instantaneous effort (kg)	Speed (km/h)
Pair Djokhore bullocks[a]	13	730	500	3.4	780	4.5
Pair Djokhore cows[a]	6	635	375	2.8	570	4.0
Pair White Peul Zebu bullocks[b]	2	770	565	——	800	——
Pair Madagascar Zebu bullocks[b]	2	650	345	3.1	750	4.5
2 Pairs Madagascar Zebu bullocks[b]	1	1300	650	3.1	more than 1000	3.8
Pair of Renitelo bullocks[b]	1	1110	590	3.9	more than 1000	4.5

[a] Head yoke for the Djokhore bullocks and cows

[b] Withers yoke for the Peul Zebus, the Madagascar Zebus and the Renitelos

Source: Adapted from FAO (1972).

conditions for so long a period without developing yoke galls, unless some type of improved harness was used[9].

Given current status of animal health management and types of harness and yokes employed, it appears that average levels of draft generated by working oxen and bulls will remain at 10 to 14% of body weight. Increases in this level will not be feasible, without physically injuring and reducing the working efficiency of animals, until improvements are made in the areas mentioned.

E. Crossbred Oxen

Crossbreeding of European (*Bos taurus*) and Zebu (*Bos indicus*) breeds has been received fairly well by farmers in warmer climates due to increased lactation length, higher milk production, and earlier age of first calving. Although crossbred oxen have been employed for draft at the National Dairy Research Institute in Karnal, India for many years (Anand and Sundaresan, 1974), the acceptance of crossbred oxen or bulls for draft by farmers has been minimal because of the general opinion that their working performance is inferior to that of the indigenous cattle (Rajapurohit, 1979) since they lack a large distinct hump and are unable to tolerate high temperatures (Roy *et al.*, 1972).

Roy *et al.* (1972) compared the plowing abilities of Hariana oxen and Jersey-Hariana crosses under wet and dry soil conditions in West Bengal. The crossbreds averaged 9.7 years and 525 kg and the Hariana 10 years and 370 kg. Plowing in wet land, i.e., rice paddies with standing water 30 to 60 cm in depth, resulted in the crossbreds plowing slightly more than the Hariana oxen, provided work commenced at 0600 hr and ended at 0800 hr. Trials conducted later in the day caused a rise in pulse and respiration rates and temperature of both groups of animals. The crossbreds exhibited the largest increase even though equivalent amounts of land were plowed by both groups. After 1000 hr, the crossbred oxen demonstrated an unwillingness to work. Plowing trials were also carried out with Hariana and Brown Swiss-Sahiwal crossbred oxen at Karnal, India. During the summer and winter months, the difference in the amount of work done in 6 hr was 7 to 11% higher for the Hariana oxen, with the difference increasing to 19% during the hot humid period of July to September (Rao, 1972). These studies indicate that as long as crossbred oxen begin work early in the day, i.e., 0500 to 0600, their working efficiency is comparable to that of the Hariana oxen over a 4 to 6 hr period.

When comparing draft potential of indigenous types vs crossbreds,

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[9] However, trials conducted by Collins and Caine (1926) using draft horses demonstrated that even with a well fitting harness and rest stops, the animals developed sore shoulders during periods of relatively high humidity (73%) and temperature (30°C) and were unable to be worked for 1 week.

consideration must be given to body weight. Hariana crosses with Jersey, Brown Swiss, and Holstein were heavier and had larger heart girths and forelimbs than pure Hariana cattle (Anand and Sundaresan, 1974). Since draft produced by oxen is largely dependent on body weight, especially, the amount of weight distributed over the front legs, crossbred oxen should be able to generate more power than indigenous animals, provided they are not subjected to thermal stress.

The lack of a hump in crossbred animals has commonly been regarded as a weakness which affects its draft performance. This is not true, as oxen in the United States and Europe are used for draft which do not possess humps. Rather, it is the design of the yokes which are employed and the line of draft maintained which require that the hump be relied upon to transfer power from the animal to forward movement of an implement. Use of the hump to pull against the yoke, e.g., the withers yoke, is not only inefficient, but moreover, puts excess strain on the cervical portion of the Rhomboideus muscle which is the primary attachment of the hump in the *Bos indicus* breeds.

The hump of F_1 crosses is positioned forward of the scapulae as compared to the hump of pure Red Sindhi which is located directly over the scapulae. Height of the hump in the F_1 cross is quite reduced with the trapezius muscle being thicker and more fan shaped than that of the Red Sindhi. The trapezius muscle in non-humped animals or *Bos taurus* breeds is not divided into cervical and thoracic parts as is the case in *Bos indicus* breeds (McDowell *et al.*, 1958). The cervical portion of the trapezius muscle in *Bos indicus* breeds which is attached to the hump is thin (Milne, 1955) and offers less strength in attachment than for F_1 crosses.

The use of improperly fitted yokes causes the beam to shift back and forth over the animal's neck; hitting the back of the head when going down steep grades or backing up; and pushing against the front of the hump when pulling loads uphill or generating large tractive efforts. As a result, friction occurs which causes yoke galls to develop. This injury is not only painful to the animal, but reduces working efficiency and if left untreated can permanently disable the animal (Alur, 1940). While crossbred oxen are not immune to such injuries resulting from poorly seated yokes, less strain is placed on the Rhomoboideus muscle because of a thicker trapezius muscle which covers a larger area at the anterior base of the hump, thereby, allowing for pressure exerted against the hump to be distributed across a larger surface.

G. Castration and Training of Oxen

Temperament, physical development, and training are three criteria which largely determine the usefulness of animals for work.

Age of castration varies, ranging from 0.5 to 5.5 years (Table 13). It is recommended that castration be done between the ages of 1.5 to 2 years, since performing the operation earlier or later only reduces

Table 13. Usual age and weight for initiation of training for work in Africa and Asia

Breed or type	Age castrated (yr)	Age trained for work (yr)	Weight (kg)		Mature weight (kg)
			1 yr	2 yr	
Adamawa	—	—	145	190	350-500
Azaouak	—	—	—	—	350-500
Maure	—	2.5-4	—	—	250-350
Northern Sudan Shorthorn	—	1.5-4	80	135	300-410
Shuwa	—	2.5-3	145	240	350-400
N'Dama	1.5-2	2-3	84-136[a]	200-300	280-410[a]
Senegal Fulani	—	5	—	—	300-415
Ankole	—	2.2-5	140	225	300-410
Bukedi	—	2-3	90-120[a]	160-175[a]	350-450[a]
Bororo	2.5-4	2-4	—	—	350-400
Lugware	—	3	85-100	150-200	300-350
Madagascar Zebu	—	4	175	260	300-450
Kankrej	.5-1	3-4	175	250	360-550
Nagori	.5-.8	3	112[a]	217[a]	350-360[a]
Ongole (Sumba)	—	3-3.5	215	350	540-680
Khillari	5-5.5	2-3	—	—	450-635
Lohani	3-3.5	3-3.5	—	—	270
Siri	4	4	150-185	200-230	315-540
Krishna Valley	3-4	2.5	150	250-275	490-519[a]

[a] Indicates weight recorded on government research stations or stock farms.

Source: Adapted from Joshi and Phillips (1953); Joshi *et al.* (1957); I.C.A.R. (1960); Oyenuga (1967); FAO (1972).

physical development (FAO, 1972).

Training for work also varies. In Africa and India, cattle are usually trained between the ages of 2 to 4 years (Joshi and Phillips, 1953; Joshi *et al.*, 1957; Nourrissat, 1965; Laurent, 1968; FAO, 1972; Achiya and Udundo, 1975), although age may range from 1.5 to 5 years (Table 13). Cattle are trained for logging in Chile at approximately 3 years of age, while oxen in areas of Southeast Asia commence training at 2 to 2.5 years (Williamson and Payne, (1978). In Indonesia, cattle are usually not considered suitable for work until 3 or 4 years of age (Rollinson and Nell, 1973). Training earlier than 2.5 years is not advised unless animals are well fed. Working an animal before its bone structure, joints, and muscles have had a chance to properly develop may result in injury, thus, reducing the usefulness for work (FAO, 1972).

The time required to properly train an animal depends on such factors as the length of the training sessions, the skill of the trainer, methods used, age, temperament, and the type of job, e.g., plowing or carting. Training can be accomplished in as little as 3 days or extend through one full crop year, depending on whether or not an animal is docile and settles quickly into the program (Laurent, 1968). Methods of training are described by FAO (1972) and Achiya and Udundo (1975).

F. Working of Cows

Studies on the use of cows for draft in either temperate or tropical regions are few; however, cows are commonly used in Egypt and Indonesia where a shortage of bulls or bullocks has existed (Lall, 1949; Rollinson and Nell, 1973). Experiments in Germany with cows of the Red Spotted Mountain breed showed there was little effect on milk yield when performing light work for no more than 5 hours per day (Kolacek, 1933). Cows employed for heavy work exhibited a substantial loss in daily milk yield (Krautforst, 1947; Humbert, 1948; Haring et al., 1956). Tornede (1939) reported that light working of cows stimulated milk production, but that heavy work could cause up to 80% decrease in yield. Kleisch and Neuhaus (1948) reviewed data from 69 farms on which lactating cows were regularly used for draft. They estimated that milk loss due to work for a normal half day (approximately 5 hr) was 10 to 20%. Average milk yield per lactation of cows worked for 700 to 1000 hr was 4066 kg with 3.2% butterfat, whereas, cows not worked yielded 4344 kg of milk with 3.3% butterfat. This is in agreement with studies done by Schmidt et al. (1952) of 59 working cows on 18 farms. Other experiments carried out over a period of 6.5 months with milking cows of the Bernese-Hanna breed weighing 600 kg, showed that duration of work had a greater effect than intensity of work in lowering milk yield. High yielders dropped more than low yielders. Extremely fatigued animals required more than 32 hr for milk yield to return to normal after work (Kallbrunner, 1941).

Shu et al. (1964) demonstrated that first and second cross female progeny of Holstein and Syh-Yang cattle were able to pull loads of 255 and 300 kg, respectively, in comparison to native Syh-Yang cows which pulled 238 kg. The study indicated that first cross cows, producing 5 kg of milk per day, could be used for draft without serious decline in milk production.

Cultivation trials using cows were carried out by Nourrissat (1965) at the Centre National de Recherches Agronomiques de Bambey, Senegal. Animals weighing 300 kg were worked for 350 hr per year and produced 600 liters of milk over an 8 month lactation period. Monnier (1965) reported that cows can be utilized for light cultivation, e.g., weeding, seeding of crops, provided the draft requirement does not exceed 80 kg. However, in order to generate this amount of draft, it is often necessary to hitch two pairs of cows together.

There are several points which can be raised concerning the utilization of cows for draft. Observations cited, were conducted in temperate regions or on research stations in the tropics where availability of feed was not a problem. Both good management and type of feeding, i.e., additional feeding for heavier work, played an important part in sustaining milk production (Tornede, 1939; Krautforst, 1947; Schmidt et al., 1952; Nourrissat, 1965). Experimental studies in Pakistan with female Swamp buffaloes used for draft, have indicated that milk production could be maintained provided that adequate rations could be supplied and that the animals were worked under favorable environmental conditions (Rizwan-ul Muqtadir et al., 1975).

Stall feeding of cows and oxen reduces their energy requirements for maintenance. Normal exercise of cattle during grazing on good quality temperate pastures can increase maintenance energy expenditures 15 to 40% (Reid, 1958; Waldo, 1961; Blaxter, 1962). Lower quality pastures force animals to travel larger distances while grazing, thus increasing the need for thermal control. Depending on pasture conditions, maintenance requirements of grazing animals may be as much as 170% of the requirements for stall fed animals (VanSoest, 1981). Such an increase in maintenance reduces the energy available for both work and milk production.

The working of cows before conception and during early gestation necessitates that adequate energy be provided to insure reproductive efficiency. Data gathered from 5,188 farms in Germany, using 1,777 cows on a regular basis for draft,indicated that fertility was 6 to 7% lower in those animals worked (Tierzucht, 1949). Parturition at the onset of the rainy season or into the dry season by working animals has resulted in calves being underweight (Nourrissat, 1965).

It appears that further studies should be conducted under conditions and circumstances more similar to those being experienced by traditional farmers in order to better evaluate the capabilities and limitations of using cows as draft animals. Current research does not support the thesis that cows can be employed for draft without encountering adverse effects on lactation, reproduction, growth, and general health given the present level of livestock management and available resources.

H. Camel

There are approximately 17 million camels in the world, of which over 71% are in Africa with the remainder distributed mostly in Asia (FAO, 1978). The one-humped camel (Camelus dromedarius) referred to as the dromedary or Arabian camel is the prevailing species found in the desert areas of Africa, Arabia, Australia, and India. The two-humped (Camelus bactrianus) or Bactrian camel is able to withstand colder temperatures than the dromedary and is the predominate species found in Central and Northern Asia. The average body weights of mature Bactrian males and females are 632 and 497 kg (Cerenpuncag and Davaa, 1967), whereas, mature dromedaries range from 370 to 600 kg for males and from 350 to 520 kg for females (Iwema, 1960; Wilson, 1978).

It is possible to define two main types of dromedaries on an environmental basis; mountain and lowland (Matharu, 1966; Leupold, 1968). The former are coarse boned and compact with a shoulder height of 1.8-2 m vs 2.2 m for the lowland type. The latter include large dromedaries of the river zones which are used for packing and draft and the fine-boned, thin skinned desert camels employed for riding.

The camel is most widely used for riding and transporting of merchandise, but is also used for plowing, providing power for Persian water wheels, sugarcane presses, different types of mills, and pulling of carts (Knoess, 1977). A saddle is usually employed for both packing and pulling. Saddles vary from region to region and according to work being performed.

Both males and females are used for work. Females can continue at light work during the first 8 months of gestation (Podberezkin, 1951). Males are castrated between 3 and 6 years. Castration at 5 to 6 years is recommended to permit maximum physical development. Although castrates are not affected by rutting season, they are unable to bear as heavy loads as intact males. Training of camels for work normally commences at 2 to 4 years (Podberezkin, 1951; Iwema, 1960; Matharu, 1966) with full utilization ranging from 4 to 7 years (Leonard, 1894; Cross, 1917; Phillips et al., 1945; Matharu, 1966). Age at time of training and mature working level is dependent on species, type, nutritional status, physical development, and work to be performed, i.e., riding, packing or draft. Camels should not be worked on a year round basis, but should be given a period of rest each year, ideally during the rainy season when working conditions are sub-optimum and forage growth begins to improve (Matharu, 1966).

Bactrian camels in China are reported as capable of traveling 25 to 40 km per day on long journeys and up to 85 km on short trips in 24 hr. Strong camels can carry loads of 275 kg and cover 1,150 km in 30 days. Average loads are 140 kg at the beginning of the working season decreasing to 120 at the end (Phillips et al., 1945). Podberezkin (1951) stated that two Bactrian camels yoked together could pull a total weight of 1400 kg, including the load and wagon. Dromedaries in Pakistan carry loads of 362 to 435 kg at a rate of 4 km per hr (Yasin and Wahid, 1957). Riding camels carrying a rider and a load of 55 kg could travel at 8 to 10 km per hr on level ground (Leupold, 1968). Matharu (1966) recommended that animals carrying loads of 180 kg not be allowed to work continuously more than 8 hr per day or 6 hr while traveling at a speed of 3.2 to 4.8 km per hr without rest, and the distance covered per day on level ground should not exceed 32 km[10/]. A pair of Turkestan camels were able

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[10/] This is the maximum load and work capacity recommended for military camels in India (Matharu, 1966). Loads of 163 kg per camel were maintained by the Sudanese military (Wilson, 1978). Loads of over 200 kg were carried by dromedaries on an official exploration party across the South Libyan desert in 1927 (Newbold and Shaw, 1928).

to pull a wagon with a load of 908 kg. Individually they were able to bear loads of 200 to 250 kg and travel at 4 to 5 km per hr or 35 km per day (Epstein, 1969). McKnight (1969) gave data which agrees with Leupold (1968) and Yasin and Wahid (1957). In addition, he wrote that camels in Australia were often hitched in pairs, rarely in trios. Six or eight animals made up most teams, although occasionally 10 or 12 pairs would be joined together to shift an unusually heavy load. Camel teams were clearly superior during the drought years because much of the loading space in wagons drawn by horses and oxen had to be taken up with feed; as a result, the feeding rates charged, in addition to the normal freight charges, would double the total cost to the shipper.

Two male Afar camels in Ethiopia, weighing 430 and 371 kg, were separately hitched to a reversible moldboard plow. They each were able to plow 1 ha of land to a depth of approximately 16 cm in 20 hr, working 7 hr a day (Knoess, 1977).

Wilson (1978) conducted plowing trials with camels in Southern Darfur, Sudan. A spring balance was placed between the camel and the plow to determine the draft developed. A camel could produce approximately 1 hp when pulling a plow at a depth of 15 cm and could plow about 1 ha in 11.3 hr. Other measurements showed that a camel could generate 1.2 hp while operating an oil mill. The conclusion is that camels are capable of providing substantial power for agricultural production.

I. Elephant

Elephants are utilized as draft animals in the forest areas of Burma, Thailand, India, and Sri Lanka. They haul felled timber out of the forests to the flatlands where it can be loaded onto trucks or floated down rivers or streams to mills or railheads. Male elephants weigh over 2700 kg and are 2.5-2.7 m in height. Females are slightly smaller (Ferrier, 1947; Singh, 1966). Type of work performed by an elephant in forest areas is dependent on age. Training of animals usually commences at 3 to 5 years (Fischer, 1979) with the most productive working period being from 30 to 46 years (Table 14).

The amount of work an elephant can accomplish is dependent on its physical condition, size of timber, condition of the drag paths, and availability of feed in the vicinity of the logging area (Ferrier, 1947). Animals are commonly worked 5 days per week with the number of hours worked dependent on the time of year, i.e., animals coming from a layoff during the hot season are worked only 4 hr per day the first week, 5 to 6 hr per day the second week and 8 hr per day thereafter. The onset of hot and humid weather will cause the period of work to be reduced to 5 to 6 hr. When animals are "aunging", they will often be worked more than 8 hr and then given a period of rest after the operation has been completed.

Carrington (1958) reported that an elephant can haul logs weighing 900 kg or more, and two elephants working as a team can haul 4500 kg. Ferrier (1947) stated that elephants are able to exert a draft approximately equal to 72% of that of a mature horse relative to body weight.

Table 14. Work done by elephants utilized in timber operations

Age (yr)	Type of work performed
5-16	Training and light transport duties
16-24	Light extraction of small logs on level areas
24-30	Hauling logs over fairly rugged terrain
30-38	Heavy logging operations in rugged areas, aunging
38-46	Heavy logging operations in moderate terrain
46-53	Hauling of logs on flatlands or with wheeled dolly
53-60	Light work and minor transport duties

Source: Adapted from Ferrier (1947).

On the premise that the amount of draft a horse can develop is equal to 10 to 12% of body weight, a 725 kg horse can generate a tractive pull of 73 to 90 kg, while an elephant weighing 3000 kg could be expected to produce a tractive effort of 216 to 260 kg. The weight of an elephant increases approximately 45 kg per 2.5 cm increase in shoulder height above 2.5 m and decreases about 34 kg for every 2.5 cm below this level (Ferrier, 1947).

In order to utilize an elephant's strength most efficiently and to prevent physical injury, special types of harness, block and tackle and wheeled drays are used for logging[11]. Elephants are also hitched together in tandem and as one and two paired teams to move heavy logs or pull timber across muddy areas or up steep slopes. Two animals having tusks should not be hitched in tandem due to possible injury if a chain, cable or harness breaks or one of the animals falls (Ferrier, 1947).

Elephants employed to transport baggage usually weigh less than elephants used for logging, although older elephants which have been "retired" from logging are sometimes used. Baggage elephants can cover 24 km on flat ground and 14.4 km over hilly areas during the rainy season in 4.5 to 5 hr. Animals benefit when journeys of this distance or greater are broken in two, allowing for a few hours rest. Elephants can carry loads of 16 to 25% body weight, depending on their size and type of saddles used. Infrequently, an animal will be found which can travel at a rate of approximately 6.4 km per hr, although an average pace for a baggage elephant is less than 5 km per hr (Ferrier, 1948; Singh, 1966).

Elephants are also used for plowing and carting in certain areas of South and East Asia. Singh (1955) reported that an elephant could plow

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[11] For a detailed description of harness used and design of tackle, see

nearly 1 ha of land pulling a 2-bottom moldboard plow at a depth of 15 cm or harrow 2 ha of land pulling a large harrow in a 3 to 4 hr period. However, extensive use of the elephant in this particular capacity is limited because of its large feed requirement, i.e., a large animal may consume 522 to 590 kg of herbage per day. In addition, the height of the elephant requires a specially designed harness in order to pull such large implements. These two factors suggest that the number of elephants employed for agricultural purposes will be minimal, and that where possible, horses, oxen, and buffalo will be the preferred source of power.

OTHER SPECIES UTILIZED FOR DRAFT

The yak, reindeer, llama, alpaca, dog, elk, moose, sheep, and goat are used for draft at high elevations in South America, Central and Northern Asia or in taiga or tundra regions of the world. Studies to determine the level at which these animals can most efficiently generate power have been minimal.

A. Yak and Yak-Cattle Hybrids

The yak (*Bos grunniens*) is found between 3,000 to 6,000 m elevations in Nepal, Tibet, Mongolia, China, and other areas of Central Asia. It is employed predominately as a pack animal, but may be utilized for riding, carting, and plowing. Female yaks in China have been estimated to weigh 225 kg (Phillips *et al*., 1945). Novikov *et al*. (1950; cited by Epstein, 1969) gives mature body weights as 240 and 350 kg for cows and bulls in Tibet and Szechwan. One bull raised on a state farm in Tadzihk SSR weighed 650 kg at 6 years of age. According to Balezin (1959; cited by Epstein, 1969) the average weights of 29 yak cows and seven oxen from the Tsinghai border of South Eastern Kansu province were 212 and 541 kg. Yaks are especially adept at carrying loads of 120 to 160 kg over mountainous terrain at speeds of 2.4 to 3.2 km per hr (Reinhart, 1912; cited by Epstein, 1969; Phillips *et al*., 1946; Zeuner, 1963). They are capable of utilizing poor quality feed and can pack loads of 50 to 75 kg for 13 to 16 km a day over several months without adverse effects. Yaks are considered superior to mules in sense of direction and ability to travel through deep snow and swamps (Phillips *et al*., 1946).

Yak-cattle hybrids are stronger and larger than local cattle or yaks, but the extent of their development and conformation is dependent on the geographical region from which the parent stocks are chosen[12]. Hybrid vigor is usually obtained by crossing male cattle with female yaks. Male hybrids are accepted to be sterile (Phillips *et al*., 1945). A hybrid bull

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A.J. Ferrier, *The Care and Management of Elephants in Burma* (London: Messrs. Steel Brothers and Co., Ltd., 1947), p. 55-61.

[12] See Epstein, *Domestic Animals of China* (London, Morrison, and Gibb Ltd., 1969), pp. 23-25 and R.W. Phillips, R.G. Johnson, and R.T. Moyer, *Livestock of China* (Washington, D.C., U.S. Government Printing Office, 1945), pp. 73-76.

in the USSR attained a weight of 765 kg and two female hybrids averaged 311 kg with eight castrated male hybrids averaging 491 kg (Epstein, 1969).

B. Reindeer

Reindeer (Rangifer tarandus) can be found from the coastal areas of Northern Scandinavia, across the Siberian tundra, south to Northern Mongolia and the Altai Mountains and from Northeastern China along the Argun River eastward to the Bering Sea and across into the North American tundra region.

Domesticated reindeer employed as pack animals are usually driven in single file following a trained animal and a guide. The animals are often linked together; each tethered by the bridle to the saddle of the reindeer in front (C.D.I., 1922; Forde, 1961). Pack bags made from reindeer hides weigh 2 to 3 kg; their capacity is 25 to 40 kg. Pack saddles weigh 5 to 7 kg and normally last 4 to 5 years. Saddles are divided into three groups according to size and structure of the saddle tree: ordinary, heavy duty, and children's (cradle-pack saddle) (Zhigunov, 1961). Although animals can bear loads up to 100 kg, average loads including the saddle range between 30 to 70 kg. C.D.I. (1922) reported that deermen in Siberia use extra reindeer in order to keep the loads light; the objective being speed of travel: whereas, in Alaska, emphasis appears to be on amount of weight carried. Grown bucks or geldings (125-140 kg) are capable of packing nearly 70 kg for 80 km over very rough terrain. Mature females can be employed as pack animals,although maximum loads rarely exceed 30 kg (Forde, 1961). Epstein (1969), citing Herre (1955) and Maenchen-Helfen (1936), stated that reindeer can carry 40 kg for 4 to 5 hr before resting. Load standards for pack reindeer traveling over various types of terrain are in Table 15.

Reindeer used for riding (125-140 kg) in the USSR are outfitted with a "soft fixed" riding saddle. Average weight of the saddle including a load is 67 to 70 kg, with length of service being 3 to 4 years. Normal distances traveled daily on a year round basis can range from 50 to 75 km. Reindeer are the only draft animals which are capable of working throughout the year in the trackless taiga and tundra. They require no special fodder supplies nor arrangements for fodder transport as they are able to utilize existing vegetation (Zhigunov, 1961).

There are basically two types of sleds pulled by reindeer; lashed and solid. The lashed sled is assembled by tying the supports in pairs with leather straps. Loaded, weight may vary from 175 to 230 kg. Solid sleds for freight haulage are of two kinds, regular and reinforced. Regular sleds are built mainly to carry loads of camping equipment of up to 200 kg. Reinforced sleds are employed for transporting timber, firewood, barrels, machinery, and other heavy loads. As many as four reindeer may be harnessed together to pull sleds depending on the load being pulled and sled design (Zhigunov, 1961).

Geldings and stags (115 to 120 kg) are used for hauling freight; does are seldom used. Reindeer can travel at an average speed of 4 to

Table 15. Load standards for sled and pack reindeer according to ground and road surface

Condition of road or trail	Speed km/hr	Distance (km)		Maximum load of sled per reindeer (kg)	Percent body weight of load packed
		Daily	Monthly		
Good winter road	5	25	500	150	—
	7	35	700	100	—
	9	45	900	75	—
Average winter road	5	25	500	100	—
	7	35	700	75	—
	9	45	900	50	—
Poor winter road, virgin soil or marshy summer road	4	20	400	75	—
	6	30	600	50	—
	8	40	800	35	—
Good trail, hard ground, medium rugged terrain	5-7	35	700	—	40
Ordinary trail, mountains, forests, and boggy soil	5-7	35	700	—	30
No trail, boggy soil, swamp	5-7	30	600	—	20

Source: Adapted from Zhigunov (1961).

5 km per hr pulling loaded sleds. Animals drawing a light load can maintain a speed of 8 to 10 km per hr. Zhigunov (1961) separates load speeds into three categories: the "postal trot" of 10 km per hr, the "load trot" of 6 to 7 km per hr and the "walking pace" of 4 to 5 km per hr. Reindeer can pull loads weighing 45 to 150 kg depending on trail conditions and can cover 32 to 40 km per day (Table 15) (Phillips et al., 1949; cited by Epstein, 1969).

Preliminary tests for endurance, obedience, and other useful working qualities are carried out with potential pack, riding, and freight reindeer. Freight reindeer are harnessed in pairs to a sled which is loaded until its weight corresponds to 100 to 150 kg per animal. Pack reindeer must be able to carry loads equal to 40% body weight (Zhigunov, 1961). Reindeer reach maturity at five years of age, although training for draft commences earlier. Animals can live 12 to 15 years of age and may be worked until age 10 (Forde, 1934; cited by Epstein, 1969).

C. Llama and Alpaca

The llama (*Lama glama*) and alpaca (*Lama pacos*) belong to the New World camelids and are commonly found at high altitudes of 2400 to 4000 m in Peru, Bolivia, Argentina, and Chile. Male alpacas are rarely used as pack animals, except where there is a scarcity of llamas. Alpacas cannot carry as heavy loads as llamas and are primarily utilized for their high quality wool.

Llamas, like the yak, are heavily depended upon for transporting goods and supplies, e.g., potatoes, firewood, salt, and mined ore, over rugged topography with their wool and meat products ranking second in importance. Only males are used for packing. Animals attain maturity at approximately 2 years of age (Cardozo, 1965; Iniguez, 1980) and weigh 85 to 120 kg. Llamas are capable of transporting loads of 25 to 50 kg for a distance of 40 km a day over a period of 20 to 30 days (Link, 1946; Fernandez-Baca, 1978; Iniguez, 1980).

D. Dog

Sled dogs are a reliable source of power for hauling people and freight over land and sea-ice in areas of the Arctic and Antarctic. Both pack and sled dogs are employed by hunting and fishing peoples in the taiga regions along the East Siberian coast lands and across North America to Greenland (C.D.I., 1922; Forde, 1961).

Pack and sled dogs are commonly referred to as "huskies", although there are basically four major breeds that are recognized: Alaskan Malemute, Eskimo and Siberian Husky, and Samoyede.

Average weights of male and female sled dogs range from 23 to 43 and 18 to 23 kg. Dogs are trained from 6 months to 1 year of age and are at their peak condition for hard work at 3 to 6 years. The normal life span for sled dogs is 8 or 9 years, although dogs showing signs of osteoarthritis may have to be retired at an earlier age (Bostelmann, 1975).

The use of females in teams is usually based on driver preference. Teams comprised of all females are reported to be very adequate for pulling light loads over short distances at relatively fast rates (U.S. War Department, 1944). It is common to have a bitch or two in a team to reduce fighting between males. Bitches trained as team leaders help to act as an incentive for the males, preventing them from becoming bored when traveling through monotonous regions and when making rigorous ascents over rough terrain.

Taylor (1957) used a strain gauge to measure the draft generated by 9 sled dogs, each weighing an average of 39 kg. The hp generated per animal when pulling as a team for the largest regular load was 0.16. The maximum instantaneous effort exerted by the team was approximately 270 kg. Draft produced while walking was found to be inversely proportional to speed over a range of 75 to 110 kg. Trotting trials with light loads of 10 to 55 kg showed a direct proportion between draft and hp developed. Maximum energy expenditure of the team was nearly equal when generating drafts of 55 to 95 kg while trotting and walking, respectively. Such findings are similar to those reported by Brody (1945) for horses and by Devadattam and Maurya (1978) for oxen, and tend to indicate that sled dogs are more efficient working at a given hp pulling a heavy load while walking, than pulling a light load at a trot or gallop.

Dogs employed for rapid transport (sometimes referred to as messenger teams; U.S. War Department, 1944) can pull loads, including the sled, of approximately 23 kg per animal. Freight teams, made up of larger and heavier dogs, are capable of pulling weighted sleds averaging 45 kg per animal at speeds of 4.8 to 8 km per hr. Taylor (1955; cited by Bostelmann, 1975) reported that sled loads averaging more than 115 kg per dog were too heavy for teams and required more frequent periods of rest. Well maintained teams can travel 80 to 95 km per day, although normal distances covered daily average 16 to 40 km.

Dogs used for packing are generally heavier than those hitched. Pack dogs normally weigh more than 35 kg, with weights of 50 to 60 kg preferred. They are able to carry 16 kg for a period of several days over rugged landscape without any adverse effects if properly maintained. They can bear loads of 23 kg per day for one to two days at a time (U.S. War Department, 1944).

E. Elk and Moose

Domesticated elk (Alces alces) and moose (Alces americana) are used as draft, riding, and pack animals in the northern taiga and tundra regions of Europe, Asia, and North America. An experiment station was established more than 20 years ago in the Pechero-Ilychskii Game Reserve in the U.S.S.R. (Jurgenson, 1953; Knorre, 1959; Anon. 1974) to determine the potential of large scale domestication of elk for draft and the production of meat and milk. Studies have shown that because the elk is naturally a slow moving animal, it is better utilized for riding or packing, i.e., carrying dung, rather than for draft, i.e., pulling a sled or travois (Jurgenson, 1953). However, Lihacev (1962) found that domestication of the elk for either transport or draft was met with little success. Instead, the most promising use of the animal was for meat and leather. Mature elk and moose can attain body weights of 680 to 820 kg (Cole and Ronning, 1974), although animals produced for meat are normally slaughtered at 500 kg (Anon., 1974).

F. Sheep and Goat

The use of sheep and goats as draft animals (except for amusement)[13] appears to be limited to the Himalayan regions of Central Asia, although domestic goats have been used as pack animals in Western Europe (Zeuner, 1963). The Chanthan breed of sheep and Kel breed of goat are utilized for packing within and north of the arid regions of Kashmir (Mason, 1974). Large sheep of the Hunia breed are able to carry loads of salt and borax weighing up to 18 kg over snow covered passes in Tibet (Zeuner, 1963; Epstein, 1969). In the Himachal Pradesh and Punjab states of India, male sheep of the Rampur Bushahr or Bushier breed are castrated and used as pack animals. Wethers are reported to carry loads of 2.3 to 3.2 kg (Lall, 1950; cited by Williamson and Payne, 1978). Goats of the Chigu breed, in Punjab, India, are able to pack loads weighing 4.5 to 18 kg for up to 15 km per day (Mason, 1974).

Available data indicates that mature sheep and goats can pack loads equivalent to 12 to 23% of their body weight. These values are less than those of 27 to 41% recorded for pack dogs.

COMPARATIVE DRAFT AND PACKING PERFORMANCE

Percentage of body weight exerted as draft or packed by animals is variable. Wide ranges occur among reported values for maximum performance tests and daily work due to differences in methods of measurement and duration of experiments. While tests of maximum performance indicate animal reserve strength, they do not reflect ability to work for extended periods of time. Estimates of draft and packing capacities of species reviewed have been summarized (Table 16, 17). In general, most animals can develop a draft of 10 to 14% of body weight when traveling at a speed of 2.4 to 4.0 km per hr (Table 16). An increase in speed will cause a reduction in draft exerted or legnth of work period. However, hp produced will increase due to a faster rate of work; oxen (450 kg) traveling 2.4 km per hr and developing a draft of 64 kg, generate 0.6 hp. Increasing speed to 4.0 km per hr, reduces draft to 45 kg, but increases hp to 0.7.

Large differences exist between species regarding percentage of body weight that can be packed. Horses and mules can pack 12 to 15% of body weight while camels and reindeer are reported as capable of carrying loads equivalent to 27 to 40% (Table 17). Saddle design and type will influence weight carried. Recommendations for pack animals, especially camels, are inconsistent. More research will be needed before

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[13] In the United States, a team of six Hampshire sheep have been able to generate a tractive effort large enough to pull a pick-up truck (Jones, 1980)

Table 16. Estimates of draft capacity of several species with drawn implements at low and high speeds

Type of animal	Mature weight (kg)	Low speed			High speed		
		Speed (km/hr)	Draft (kg)	hp	Speed (km/hr)	Draft (kg)	hp
Horse							
light	385	2.4	48	.4	4.0	39	.6
medium	500	2.4	63	.6	4.0	50	.7
heavy	850	2.4	106	.9	4.0	85	1.3
Mule							
light	200	2.4	32	.2	4.0	20	.3
heavy	600	2.4	96	.9	4.0	60	.9
Ass							
light	190	2.4	30	.3	4.0	19	.3
heavy	300	2.4	48	.4	4.0	30	.4
Ox							
light	210	2.4	30	.3	4.0	21	.3
medium	450	2.4	64	.6	4.0	45	.7
heavy	900	2.4	129	1.1	4.0	90	1.3
Cow							
light	200	2.4	20	.2	3.5	16	.2
heavy	575	2.4	58	.5	3.5	48	.6
Buffalo							
light	400	2.4	56	.5	3.2	40	.5
medium	650	2.4	91	.8	3.2	65	.8
heavy	900	2.4	126	1.1	3.2	90	1.1
Camel (dromedary)							
light	370	3.5	50	.6	4.0	37	.5
heavy	600	3.5	84	1.1	4.0	60	.9
Elephant							
medium	2900	2.0	230	1.7	—	—	—
heavy	3600	2.0	285	2.1	—	—	—
Dog							
light	21	5.4	6	.1	8.5	2	.06
heavy	43	5.4	12	.2	8.5	4	.1

Table 17. Estimates of capabilities of various species for pack loads over 6 to 8 hr per day

Type of animal	Mature weight (kg)	Speed (km/hr)	Load (kg)	
			Average	Maximum
Horse				
light	350	5.6	40	55
medium	500	5.6	60	75
heavy	635	5.6	75	95
Mule				
light	270	7.2	34	50
medium	500	7.2	63	90
heavy	650	7.2	82	115
Camel (Bactrian)				
male: medium	630	4.0	175	250
heavy	725	4.0	200	290
female: medium	500	4.0	135	200
heavy	575	4.0	155	230
Camel (dromedary)				
male: light	370	4.0	100	150
medium	500	4.0	140	200
heavy	600	4.0	165	240
female: light	350	4.0	96	140
medium	435	4.0	120	175
heavy	520	4.0	145	210
Elephant				
medium	2900	3.5	460	580
heavy	3600	3.5	575	720
Yak				
male: light	350	2.8	85	110
heavy	650	2.8	160	205
female: medium	225	2.8	55	70
heavy	300	2.8	75	100
Yak-cattle hybrid				
light	300	2.8	75	100
medium	500	2.8	120	160
heavy	750	2.8	180	240

Table 17 (con'd)

Type of animal	Mature weight (kg)	Speed (km/hr)	Load (kg) Average	Load (kg) Maximum
Buffalo				
light	400	3	50	60
medium	650	3	82	100
heavy	900	3	110	140
Ox				
light	250	3.5	30	65
medium	450	3.5	55	115
heavy	700	3.5	90	175
Reindeer				
medium	125	5	30	50
heavy	140	5	35	56
Llama				
light	85	4.5	25	35
heavy	120	4.5	40	50
Dog				
light	35	6	9	14
medium	50	6	14	20
heavy	60	6	16	25
Sheep				
medium	50	2.5	6	12
heavy	70	2.5	8	16
Goat				
light	40	2.5	5	9
medium	50	2.5	6	12
heavy	75	2.5	9	17

optimum loading guidelines are adequately established. Studies should include assessment of current load recommendations and energy needs based on weight carried, speed of travel, and working period.

NUTRIENT REQUIREMENTS OF DRAFT ANIMALS

Age, sex, amount of draft generated, and duration of work will determine energy requirements. Mature oxen for example, have requirements for maintenance and work, while immature animals and pregnant or lactating cows employed for draft have additional needs. Many of the estimated requirements in the literature are based on standards used for draft of nonworking animals in temperate regions and are often not representative of animal needs under "actual farming" conditions. This section examines available data on energy requirements for working animals and attempts to categorize three areas: maintenance, growth, and work. The effects of physical conditioning and temperature on energy needs are also discussed.

A. Maintenance

Energy requirements for draft animals at maintenance level are similar to those for non-working animals. Daily requirements to maintain 450 kg draft animals have been calculated from previous reports (Table 18). In order to provide consistency, the unit total digestible nutrients (TDN) has been selected. Estimated requirements average 3.3 kg of TDN. Differences between values may lie in the methods used to determine requirements.

Table 18. Estimates of energy needed for maintenance of draft animals weighing 450 kg

Country/Region	TDN[a/] (kg)	Species	Source
Europe	3.3	Ox	Kellner (1917)
United States	3.2	Horse	Morrison (1947)
United States	3.1	Horse	N.R.C.[b/] (1966)
United States	3.5	Horse	N.R.C. (1973)
India	3.2	Ox	Dharmani _et_ _al_. (1946)
India	3.4	Ox	Lander (1949)
India	4.2	Buffalo	Lander (1949)
India	3.4	Ox	Sen (1966)
West Africa	2.6	Ox	FAO (1972)

[a/] Values were converted to TDN assuming that TDN = carbohydrate + protein + 2.25 (fat), (Crampton and Harris, 1969) and 1 forage unit (F.U.) is equivalent to the energy derived from 1 kg of barley (VanSoest, 1981); thus, 1 F.U. = 0.73 kg of TDN (Morrison, 1956).

[b/] National Research Council.

The same methods cannot be employed to measure maintenance needs in mature and growing animals due to under nutrition which occurs as the animal grows "at the expense of its own body" (VanSoest, 1981). Given that maintenance needs of animals are partially set by the level of body reserves available, an animal lacking adequate energy for work will utilize these reserves to meet energy needs, resulting in weight loss.

B. Growth

Although animals are commonly trained for work from 2.5 to 4 years (Table 13), it is unlikely they will have attained their mature weight. Employing immature animals for draft necessitates that adequate energy be provided for growth. Values reported for immature animals are few and variable. Lander (1949) recommended that cattle (147 to 226 kg) be fed 1.1 to 1.3 kg of TDN above maintenance for a daily gain of 0.45 kg. Sen (1966) reported that 1.3 to 1.7 kg of TDN were required above maintenance for growing cattle (150 to 450 kg). Wrigley (1971) gave estimates of 0.9 to 1.1 kg of TDN above maintenance for immature oxen. The National Research Council (N.R.C., 1976) recommended that immature cattle (100 to 400 kg), gaining 0.5 to 1.0 kg per day, be fed 0.5 to 3.5 kg of TDN above maintenance. Calculations from energy values given by the N.R.C. (1966) for immature draft horses indicate that animals attaining mature weights of 270 to 635 kg need 0.7 to 0.8 of TDN per day, in excess of maintenance requirements.

C. Work

1. General Requirements

a. Energy

Draft horses working at a rate of 1 hp for 8 hr have a ratio of energy expenditure of rest (basal metabolism) to work of about 8 (Brody and Cunningham, 1936). This ratio is within the range of 3 to 8 given by Dill (1936) for humans doing strenuous work for 8 to 10 hr. Horses (513 kg) performing field operations, i.e., plowing, harrowing, and cultivating, had relative metabolic rates[14/] of 5.2 to 6.3 (Tatsumi et al., 1958). The relative metabolic rate of horses (549 kg) in the USSR, when generating a draft of 15% body weight at a speed of 5.8 km per hr, was about 9 (Nadal'jak, 1961[a]). Four breeds of heavy draft stallions (748 kg) expended 32% more kcal per 100 kg of body weight pulling a load (draft of 130 kg) than at rest, (Nadal'jak, 1961[b]). Lantin (1964) found the relative metabolic rates of buffalo at work as 2.9 to 6.6. Ponies doing medium work (0.26 hp for 4 to 5 hr) expended energy equivalent to nearly 3 times basal metabolism (Barth et al., 1977) which is similar to other values of 3.0 to 3.5 for draft horses at light and medium work (N.R.C., 1966, 1973). According to Brody (1945), the "ratio of sustained hard work to rest energy is approximately the same in horse and man, and probably independent of size or of species as such." In general, energy expenditure of animals at work is 3 to 8 times that of

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[14/] Relative metabolic rate = $\frac{\text{energy expended at work}}{\text{energy expended at rest}}$

basal metabolism, but actual relative metabolic rates will be affected by frequency and level of work.

The classifications light, medium, and heavy are commonly used to designate nutrient requirements of working animals (Kellner, 1917; Dharmani, 1946; Lander, 1949; Monnier, 1965; Nourrissat, 1965; N.R.C., 1966, 1973; Sen, 1966; Wrigley, 1961; FAO, 1972). These classifications are based on the number of hours work was performed, but do not consider that energy requirements vary directly with the rate at which work is accomplished, i.e., work done for a specified period of time at one rate will require more or less energy than work done at a different rate. Applying a general category to work performed, based on time alone, may not adequately cover energy costs. Rather, both intensity (percentage of body weight developed as draft) and rate of work (hp) should be included when calculating energy needs.

b. Protein

Although animals at work need more than maintenance requirements, it is undetermined whether extra protein is required. Chambers and Milhorat (1928), Mitchell and Kruger (1928), Nitsche (1939; cited by N.R.C., 1973), Forbes (1945) and Kraut and Lehmann (1949; cited by Maynard and Loosli, 1969) demonstrated that increased physical activity did not "measurably" raise protein needs. Harvey et al. (1939; cited by N.R.C., 1949) found that draft horses working at rates of up to 1.27 hp for 4 hr, remained in positive nitrogen balance without increasing protein intake. While a loss of protein and other nitrogenous compounds occurs through sweating (Consolazio et al., 1963 and Watkin et al., 1948; cited by N.R.C., 1973) the amount of protein required to replace such losses has not been determined (N.R.C., 1978[b]). On the other hand, over feeding of protein may reduce working performance "due to increased heart and respiration rates and sweating" (Slade et al., 1975; cited by N.R.C., 1978[b]). Although Lander (1949) and Sen (1966) recommended increasing protein for working oxen in India, values given for working cattle in West Africa showed protein requirements as unchanged (Nourrissat, 1965; FAO, 1972). Kehar et al. (1943) found that oxen were able to work for 6 hr periods with no measureable increase in loss of endogenous protein provided the increased caloric requirement during the work period was met by carbohydrates and fats. Crampton (1964) and Maynard and Loosli (1969) suggested that the ratio of protein to energy in the maintenance diet should remain constant since widening of this ratio could depress palatability and digestibility and increase metabolic heat loss. Nutritive requirements recommended for horses (N.R.C., 1978[b]) show the percentage of protein for mature horses performing light, medium and heavy work as unchanged from maintenance. Feeding of concentrates to provide additional energy for work (and thereby, continuing to maintain fairly constant protein to energy ratio) was regarded as adequate to cover nitrogen losses from sweating. While feeding concentrates as a source of energy provides flexibility in meeting protein needs, this option is not available to the majority of farmers who rely on animal traction. The general conclusion is that an increase in protein for work above maintenance levels will not be required provided the maintenance ration is adequately balanced.

c. Minerals and Vitamins

Mineral and vitamin requirements of working animals are not firmly established; however, it is known that requirements for certain minerals, i.e., calcium, phosphorus, chloride, and vitamins, i.e., B-vitamins, increase during work (N.R.C., 1966, 1973, 1978^{b}). Ordinarily, horses acquire most of their needed minerals from pasture, roughage, and grain (N.R.C., 1978^{b}). Mineral content of such feeds will be affected by minerals, in the soil, plant species, stage of maturity of the plants, and methods of harvesting for stored forages. Mature cattle and horses usually receive adequate amounts of vitamins, when they have access to high quality roughage (N.R.C., 1973, 1976, 1978^{a,b}). Present recommendations need to be tested under actual working conditions to assess their applicability. Until more is known, current N.R.C. recommendations for cattle and horses appear adequate as a guide.

2. Work Time and Physical Conditioning

When calculating energy requirements for working animals, it is important that length of time during which an animal is actually at work be considered. The time spent standing in harness is not part of the true work period (N.R.C., 1949). This reasoning is based on data gathered from experiments on resting metabolism (Winchester, 1943; Brody *et al.*, 1943). A short term increase in energy needs occurs between periods of actual work and rest. The amount is influenced by an animal's physical condition. If an animal is in good physical condition, i.e., healthy and worked regularly, it will recuperate from oxygen debt and return to its maintenance level of oxygen consumption quicker than an animal worked infrequently (Brody, 1945). Regularly worked Vladimir draft horses required 8% less energy per 100 kg of body weight per 100 kg load drawn 1 km and had a higher tolerance to oxygen debt as compared to being worked at irregular intervals (Nadal'jak, 1961^{c}). Time required to completely return to maintenance level of oxygen consumption may take 1 to 2 hrs, even for animals regularly worked (Marinic, 1957). Experiments conducted with Polish Konik draft horses demonstrated that measurement of the pH level in an animal's blood plasma; before, immediately following, and 1 to 2 hr after strenuous work, may be used as a "supplement index" for evaluating an animal's working performance (Kownacki *et al.*, 1962).There was a negative correlation between pulse rate at rest and the maximum load Hariana oxen could pull (Mukherjee *et al.*, 1961). Energy needs of an animal increase above those required for maintenance and growth during the initial stages of training, even before any "actual work" is accomplished. Extra energy expenditure occurs when an animal resists being led or yoked in a team. Energy expended by animals during initial training periods can be equal to or greater than the energy utilized while working (Lall, 1949).

3. Influence of Temperature on Energy Requirements

Information on changes in energy needs of draft animals as a result of thermal stress is scanty. Respiration rate and body temperature of Hariana oxen increased as ambient temperature rose (10 to 28°C), while pulse rate tended to quicken as relative humidity increased. There was also a positive relationship with time (6 hr) and the three measures (Mukherjee, *et al.*, 1961). Similar studies showed a significant correlation between pulse rate and hp produced with Hariana oxen from 26 to 33°C. Animal fatigue may be brought on more rapidly by an increase in ambient temperatures and humidity than by amount of weight pulled (Devadattam and Maurya, 1978). The elevation of pulse and respiration rates and body temperature, under thermal stress, indicates a resulting rise in metabolic rate and sweating which require additional energy (McDowell, 1972). Further studies are needed on working schedules during the day to minimize thermal stress.

CONCLUSIONS

With the majority of farmers in Africa and South and East Asia relying on animals as a source of power and the reality that future supplies and availability of petroleum are uncertain, appropriate recommendations for more efficient and productive systems of employing animal draft are essential. Unfortunately, few guidelines exist for individuals working in agricultural programs who wish to upgrade this area of livestock utility, but as pointed out by McDowell and Hildebrand (1980) there is frequently a lack of interaction among government agencies which are responsible for agricultural development. They conclude that the ministries or ministry responsible for livestock are mainly concerned with animal health and meat or milk production while other organizations are concerned with crops. This results in minimal attention by governments to problems associated with animal traction.

Improved harness would permit greater draft to be generated and would provide added comfort for animals. Consideration of the physical principles, e.g., line of draft, rolling and grade resistance, which can affect the quantity of draft will allow for more efficient transfer of power from animals to implements. Studies to determine variation in draft between first and subsequent plowings or of different soil types have been minimal. It cannot be assumed that second, third, and fourth plowings will require less draft than the first. For example, Raagard (1973) found that tillage of the soil for a third time did not reduce draft from that need initially, due to late rains softening the soil resulting in the plow going deeper.

Estimated energy requirements for horses and oxen of different weights, working at various rates for 4, 6, and 8 hr are given in Tables 18 and 19. Values for horses were calculated from feeding standards compiled by Morrison (1947) and N.R.C. (1966, 1973). Quantity of TDN for three levels of intensity (percentage of body weight developed as draft) are 2.6, 3.0, and 3.5 times hourly maintenance need for each hour of work[15/]. Horses require more energy when traveling at a speed of 4 km per hr than at slower speeds, given selected working intensities. Total amount of energy needed varies according to time and rate of work. Oxen require more energy working at slow speeds developing draft equivalent to 14% of body weight than at fast speeds developing less draft (Table 19). Constants employed for calculating energy needs

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[15/] Assumed maintenance requirements as 11 to 15% above the energy cost of asal metabolism (Brody, 1945).

Table 18. Estimates of TDN needs for horses of various sizes working at different rates for 4, 6, and 8 hr periods

Weight (kg)	Draft (kg)	Draft[a] (% body weight)	Speed (km/hr)	hp	TDN needs (kg/time)[b]		
					4	6	8
270	27	10	4.0	.40	3.4	4.0	4.6
270	30	11	3.5	.39	3.2	3.7	4.2
270	32	12	3.2	.38	3.1	3.5	3.9
365	37	10	4.0	.55	4.2	4.9	5.7
365	40	11	3.5	.52	4.0	4.7	5.3
365	44	12	3.2	.52	4.0	4.7	5.3
455	46	10	4.0	.68	4.9	5.8	6.6
455	50	11	3.5	.65	4.7	5.4	6.2
455	55	12	3.2	.65	4.7	5.4	6.2
545	55	10	4.0	.81	5.6	6.6	7.6
545	60	11	3.5	.78	5.4	6.3	7.1
545	65	12	3.2	.77	5.1	5.9	6.7
635	65	10	4.0	.95	6.3	7.4	8.5
635	70	11	3.5	.91	6.0	7.0	8.0
635	76	12	3.2	.90	5.7	6.6	7.5

[a] Percentage of body weight developed as draft by light and heavy animals was calculated similarly, since the ability of light animals to generate a greater percentage of body weight as draft compared to heavy animals has been shown to be significant only at levels of maximum performance (Prawochenski and Piotraszewski, 1955). For extended time periods, percentage of body weight developed as draft by light animals should be within the same range as heavy animals of the same species in order for energy to be utilized more efficiently.

[b] Includes daily maintenance needs.

Table 19. Estimates of TDN needs for oxen of various sizes working at different rates for 4, 6, and 8 hr periods

Weight (kg)	Draft (kg)	Draft[a] (% body weight)	Speed (km/hr)	hp	TDN needs (kg/time)[b]		
					4	6	8
250	25	10	4.0	.37	3.3	3.8	4.3
250	30	12	3.5	.39	3.5	4.0	4.6
250	35	14	3.2	.41	3.6	4.3	4.9
300	30	10	4.0	.44	3.7	4.3	4.9
300	36	12	3.5	.47	3.9	4.6	5.2
300	42	14	3.2	.49	4.1	4.8	5.5
350	35	10	4.0	.52	4.2	4.8	5.4
350	42	12	3.5	.54	4.4	5.1	5.8
350	49	14	3.2	.58	4.5	5.4	6.2
400	40	10	4.0	.59	4.7	5.4	6.2
400	48	12	3.5	.62	4.9	5.8	6.6
400	56	14	3.2	.66	5.2	6.1	7.0
450	45	10	4.0	.67	5.2	5.9	6.7
450	54	12	3.5	.70	5.4	6.3	7.2
450	63	14	3.2	.75	5.6	6.7	7.7
500	50	10	4.0	.74	5.4	6.3	7.1
500	60	12	3.5	.78	5.7	6.7	7.6
500	70	14	3.2	.83	5.9	7.0	8.1
550	55	10	4.0	.81	5.7	6.6	7.5
550	66	12	3.5	.86	6.0	7.0	8.0
550	77	14	3.2	.91	6.3	7.4	8.5
600	60	10	4.0	.89	6.1	7.0	7.9
600	72	12	3.5	.93	6.4	7.5	8.5
600	84	14	3.2	.99	6.7	7.9	9.1

[a] IBID. (Table 18).

[b] Includes daily maintenance needs.

of selected intensities for horses were applied to oxen based on data from Dill (1936) and Brody (1945). The estimates demonstrate that similar amounts of TDN are required for different rates of work over varying time periods, e.g., a 350 kg ox generating 0.52 hp for 8 hr would require the same amount of TDN as it would when generating 0.58 hp for 6 hr.

In warm climate regions of the world it will be difficult for animals to obtain these levels of TDN while grazing on natural pasture alone, except during the early part of the wet season. This means that for most of the year supplementation will be needed for peak working performance. Unless supplemented, working animals at high rates for extended periods of time will result in the use of body reserves. Where supplements are unavailable or too high in cost, there is a dilemma on how best to match feed resources and animal needs.

Requirements for mules and asses appear similar to those given for horses (Morrison, 1947). Feeding standards for working buffalo are few (Lander, 1949); however, the TDN estimates given in this paper for oxen should serve as good approximation for meeting energy needs of buffalo working at similar rates.

APPENDIX A

African cattle employed for traction

Breed or type	Predominant region(s)	Mature weight (kg)[a/]	Draft capacity and utilization
Azaouak	French West Africa, Nigeria, and Eastern Sudan	Bulls 350-500	Excellent pack ox, especially in sandy areas. Not suitable for heavy draft
Maure	Mauritania, Western Sudan, and French West Africa	Bulls 300-400	Pack animals capable of carrying loads of 80-100 kg for 40 km in a 10-11 hr day. Suitable for draft, but are slow
Egyptian cattle	Egypt	——	Tillage, threshing and powering of Persian water wheels
Libyan (Shorthorned) cattle	Libya	Bulls 380-450	General draft work
Brown Atlas	Tunisia, Algeria, and Morocco	Bulls 250-420 Bullocks 200-400	General draft work, capable of walking 2.4-2.8 km per hr
Adamawa	Cameroon and Southeastern Nigeria	Bulls 350-500	Transportation of farm produce and tillage on moderate soils
Northern Sudan Shorthorned Zebu	Northern Sudan	Bulls 400 Bullocks 410	Tillage and carting. Pair of bulls can plow .28 ha or ridge 1.0 ha in 5-6 hr or pack 113 kg for 4-5 hr at 4.8 km per hr
Shuwa	Lake Chad area, extreme Northern Cameroon, and Eastern Nigeria	Bulls 350-400	Pack animals, medium draft qualities

Appendix A (Cont'd.)

Breed or type	Predominant region(s)	Mature weight (kg)[a/]	Draft capacity and utilization
Sokoto	French West Africa and Nigeria	Bulls 535	General draft. Slow,but docile and reliable
Fulani or Peul: Nigerian Fulani Senegal Fulani Sudanese Fulani White Fulani	West of the Senegal River to east of Lake Chad, and including part of Senegal, Mauritania, Sudan, Niger, and Nigeria	Bulls 300-350 Bullocks 330	General draft. A pair of bullocks can haul 490-540 kg in a cart at 3.2 km per hr for 6-8 hr per day
M'Bororo	French West Africa Lake Chad area, and Northern Nigeria	Bulls 350-500 Bullocks 360	Pack animals, poor temperament for draft
N'Dama	West Africa	Bulls 300-410 Bullocks 260-400	Tillage and haulage, not suitable for prolonged or heavy work
Kuri	West Africa and Sudan Savannah zone to the west and south of Lake Chad	Bulls 490-650 Bullocks 500-550	Poor draft and pack animals
Ankole	Uganda, Rwanda, Burundi, and Tanzania	Bulls 290-500 Bullocks 340-365	Energetic animals. Pair of bulls can haul 800 kg in a rubber tired cart for 16 km. Can plow in hard soil for 4-5 hr
Barotse	Northern Rhodesia	Bulls 500-600 Bullocks 490	Limited draft due to poor durability of hooves

Appendix A (Cont'd.)

Breed or type	Predominant region(s)	Mature weight (kg)[a]	Draft capacity and utilization
Bukedi	Eastern and Northern Uganda	Bulls 270-365 Bullocks 300-450	General draft, even-tempered, but slow workers
Lugware	Zaire and Sudan	Bulls 300-410 Bullocks 350-400	Good temperament and willingness to work. A pair of bullocks can haul 700-800 kg at 4 km per hr for 15 km in a 4 hr working day
Tanzanian Short-horned Zebu	East Africa	Bulls 225-310 Bullocks 200-260	Tillage
Madagascar Zebu	Madagascar	Bulls 400-450 Bullocks 400-450	Pair of oxen can haul 350-500 kg at 4 km per hr and cover 30 km in a day A team of 6 oxen can plow .5 ha in a 5 hr working day.

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[a] Based on recorded body weights and estimates using heart girth measurements.

Source: Adapted from Joshi and Phillips (1957); FAO (1972); McDowell (1972), and Williamson and Payne (1978).

APPENDIX B

Cattle employed for traction in South and East Asia

Breed or type	Predominant region(s)	Mature weight (kg)[a]	Draft capacity and utilization
Kankrej	Area surrounding Sind, Pakistan and in Gujarat and Rajasthan, India	Bulls 455-682 Bullocks 550	Fast, but powerful. A pair[c] can haul up to 1810 kg on a cart with pneumatic tires for 40 km in 10 hr. Employed for plowing, harrowing, threshing, and lifting water from wells
Kenwariya or Kenkatha	Southern Uttar Pradesh and Northern Madhya Pradesh, India	Bulls 340 Bullocks 320	Light draft and cultivation
Kherigarh	Kheri district of Uttar Pradesh, India	Bulls 270 Bullocks 250-270	Light draft and rapid transport. Estimated that a pair can haul 1350 in a cart for 45-55 km in a day at 4-6.4 km per hr
Malvi	Madhya Pradesh and Maharashtra, India	Bulls 300-315	General draft and transport
Tharparkar or Thari	Eastern portion of the Sind Province	Bulls 400-570 Bullocks 385-430	Tillage and powering Persian water wheels, carting, and packing. In the desert a pair can pull 450-680 kg on a cart with pneumatic tires and cover 32-40 km in 8-10 hr. A pack animal can carry 150-225 kg.
Bachaur	Bihar, India	Bulls 395-440	General draft, a pair of bulls can haul up to 600 kg

Appendix B (Cont'd.)

Breed or type	Predominant region(s)	Mature weight (kg)[a]	Draft capacity and utilization
Bhagnari	Northern Pakistan	Bulls 450-465 Bullocks 480-490	Powerful and used for heavy draft in irrigated areas for deep plowing. Somewhat slow, but are able to work for prolonged periods and pull heavy loads under high temperature conditions. Draft capacities similar to those of Tharparkar bullocks
Deoni	Andhra Pradesh, India	——	General draft, pair of animals able to pull 540 kg on iron-tired cart for 33 km in 10 hr
Gir	Junagarh, Bhavnagar, and Amreli districts of Gujarat, India	Bulls 320-540	Powerful draft animal, but medium-paced in movement. Performance comparable to Deoni bullocks
Nimari	Narmada Valley tract in Madhya Pradesh, India	Bulls 386-523	Capable of hauling 680-905 kg on a hard road 32-40 km in a day. With lighter loads travel at 4.8-5.6 km per hr. Perform field work for 8-10 hr per day
Red Sindhi	Sind Province of Pakistan and Gujarat, India	Bulls 385-395 Bullocks 340-405	Medium paced, steady workers for draft, transport, and packing. On dirt road, a pair can pull 680-905 kg on an iron-tired cart for 7-8 hr a day at 3.2-4 km per hr. A pack animal can carry 135-225 kg

Appendix B (Cont'd.)

Breed or type	Predominant region(s)	Mature weight (kg)[a]	Draft capacity and utilization
Sahiwal	Punjab, India and Montgomery district of Pakistan	Bulls 506-540 Bullocks 450	A pair can pull loads of 1810 kg in a cart w/penumatic tires on a hard road for 24 km in 6-8 hr of travel
Amrit Mahal	Mysore, India	Bulls 385-405	Great stamina, a pair can pull 680-907 kg at 4.8-4 km per hr for 8-10 hr without rest
Hallikar	Mysore, India	Bulls 400-490	General draft and transport
Kangayam	Southern and Southeastern area of Tamil Nadu, India	Bulls 470-540 Bullocks 520	A pair can pull 907 kg in an iron-tired cart 6.4 km per hr for up to 60 km
Gaolao	Madhya Pradesh and Maharashtra, India	Bulls 400-430 Bullocks 400	Rapid draft, a pair can travel 35-40 km in 7-8 hr pulling 450 kg. General tillage
Hariana	Eastern Punjab, Rajasthan, and Western Uttar Pradesh	Bulls 360-495 Bullocks 335-530	Fast plowing and road transport. A pair can pull 907 kg for 32 km at 3.2 km per hr
Krishna Valley	Andhra Pradesh, India	Bulls 510 Bullocks 545	Heavy draft in black cotton soils, transport
Mewati	Mathura district of Uttar Pradesh and Bharatpur, India	Bulls 465 Bullocks 360	A pair can haul 540-680 kg on an iron-rimmed cart for 24-32 km at 4.8 km per hr. General tillage work 8-10 hr a day

Appendix B (Cont'd.)

Breed or type	Predominant region(s)	Mature weight (kg)[a]	Draft capacity and utilization
Nagori	Rajasthan, India	Bulls 360 Bullocks 315	Young pair can haul 360 kg in an iron-rimmed cart on a sandy road and cover 57 km in 8 hr. Can travel for 32 km at 9.6 km per hr
Ongole	Andhra Pradesh, India	Bulls 540-610	General transport and tillage
	Java, Indonesia	Bulls 495-645 (grazing) Bulls 595-795 (stall fed)	General draft and tillage
	Sumba, Indonesia	Bulls 525 Bullocks 450	A pair can haul 1270 kg for 6-7 hr at 4.9 km per hr
Rath	Alwar and adjacent areas in Rajasthan, India	Bullocks 440-545	Powerful, a pair is capable of pulling 450 kg in heavy sand for 32 km. Able to work 10 hr a day in the field
Dangi	Western Maharashtra and Southern Gujarat, India	Bulls 364-455	A pair can haul timber at 3.2-4.8 km per hr and travel 32-38 km per day
Khillari	Maharashtra, India	Bulls 453-635 Bullocks 400-500	Able to pull 680 kg in an iron-tired cart at 6.4 km per hr for 40-48 km

Appendix B (Cont'd.)

Breed or type	Predominant region(s)	Mature weight (kg)[a]	Draft capactiy and utilization
Lohani	Eastern Pakistan and Rajasthan, India	Bulls 272 Bullocks 317	A pair can haul 450-540 kg at 4.8-5.6 km per hr and cover 24-32 km in a day
Ponwar	Pilibhit district, of Uttar Pradesh, India	Bulls 311-362 Bullocks 317	Rapid draft for tillage and transport
Siri	Areas around Darjeeling, India and in Sikkim and Bhutan	Bulls 362-544 Bullocks 315-453	General tillage, threshing. Bullocks have strong feet and can haul 907 kg up steep hills at 1.6 km per hr. Work for 8-10 hr a day
Dhanni	Jhelum and Rawalpindi area of Pakistan and Northwestern Punjab, India	Bulls 362-544 Bullocks 476-585	A pair can haul a load of 1130-1360 kg in an iron-tired cart on a rough dirt road and can cover 40-48 km in 8-10 hr. As a pack animal, can carry 136-225 kg

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[a] Based on recorded body weights and estimates using heart girth measurements.

[b] Unless indicated otherwise, a pair refers to mature bullocks.

Source: Adapted from Joshi *et al*. (1953), Indian Council of Agricultural Research (1960), and McDowell (1972).

REFERENCES

Achiya, S.C.P. and B. Udundo. 1975. The advantages and disadvantages of the "Indian Method" of training and controlling oxen. In: Proceedings Of A Workshop On Farm Equipment Innovations For Agricultural Development And Rural Industrialization. Edited by S.B. Westley and B.F. Johnston. University of Nairobi Institute of Development Studies Occasional Paper No. 16. Kabete.

Adelheim, R. and H. Schmidt. 1975. Economic aspects of ox-cultivation. In: Proceedings Of A Workshop On Farm Equipment Innovations For Agricultural Development And Rural Industrialization. Edited by S.B. Westley and B.F. Johnston. University of Nairobi Institute of Development Studies Occasional Paper No. 16. Kabete.

Alexander, E.N. 1975. Increasing the efficiency of the traditional systems of ox cultivation. In: Proceedings Of A Workshop On Farm Equipment Innovations For Agricultural Development And Rural Industrialization. Edited by S.B. Westley and B.F. Johnston. University of Nairobi Institute of Development Studies Occasional Paper No. 16. Kabete.

Alfaro, E. 1881. El Caballo, El Asno Y La Mula. Tipografia De Gonzalo A. Esteva, San Juan Letran Num 6, Cuarta Edicon, Mexico.

Ali, I. 1977. Bullock power and implements for small and marginal farms. Allahabad Farmer. 48(1):73-80.

Alur, K.R. 1940. Yokes, yoking and yokgalls. Indian Vet. J. 17(1):11-23.

Anand, U. and D. Sundaresan. 1974. Crossbred bullocks can contribute to agricultural operations. Indian Farming. 24(5):27-29.

Andromedas, J.H. and R.E. Lewis. 1977. "Appropriate Technology, Energetics and Draft Animals." Paper presented at the annual meeting of the American Anthropological Association, Houston, Texas, 2 December.

Anon. 1951. Muscular energy of men and animals. In: Mechanical Engineers Handbook, Fifth edition. Edited by S.L. Marks'. McGraw-Hill Book Co. Inc., New York.

Anon. 1972. Buffalo at the crossroads. World Farming. 14(7):10-13.

Anon. 1974. The elk as a new domestic animal. The Blue Book. 24:111.

Anon. 1978. Alimentation des bovins de trait. Essor Rurale. Bulletin de Liaison et d'Information Technique et Professionelle. 62:16-21.

Anon. 1978. Embouche de bovins de reforme de culture attelee, Essor Rurale. Bulletin de Liaison et d'Information Technique et Professionelle. 65:4-6. November.

Anon. 1979. Reflexions a propos de la traction animale. Section Machinisime. B.P.A. ORD de la 'Est, Fada N'Gourman. pp. 11-12. Jan. 9.

Apinjan, G.K., S.V. Aleksandrova, I.B. Pogosjan. 1959. [Results of testing crossbred draft horses in the Stepanavan and Kalinin Districts of the Armenian S.S.R.] Trud. erevansk. zootech.-vet. Inst., 23:339-343. Taken from: Anim. Breed. Abstr. 30:17; 1962 (Abstract no. 48).

Asian and Pacific Council. 1975. The Asiatic Water Buffalo; Proceedings From The Asian And Pacific Council/Food And Fertilizer Technology Center. Taiwan. ASPAC. August.

[Austria] 1955. [Regulations for the performance testing of Noric stud horses. (Performance testing regulations)]. Klagenfurt: Kleinmayr., 62 pp. Taken from Anim. Breed. Abstr. 24:12; 1956 (Abstract no. 36).

Aueljbekov, K. 1967. [Camel breeding - a profitable field]. Konevod. konnyi Sport., 5:6-8 Taken from Anim. Breed. Abstr. 35:670; 1967 (Abstract no. 4007).

Banta, G.R. 1973. "Comparison of Power Sources in Multiple Cropping". Paper presented at an International Rice Research Institute Saturday Seminar, Los Banos, Philippines.

Barker, R., S.S. Johnson, N. Alviar and N. Orciono. 1969. "Comparative Economic Analysis of Farm Data on the Use of Carabao and Tractors in Lowland Rice Farming." Paper prepared for the Farm Management Seminar sponsored by the Institute of Small Scale Industries, Manila, Philippines, 24 February-1 March.

Baron, S. 1968. Cheaper than tractors. In Ceres. 1(2):34-38.

Barth, K.M., J.W. Williams and G.D. Brown. 1977. Digestible energy requirements of working and non-working ponies. J. Anim. Sci. 44:585-589.

Bautista, Fe. and T. Wickham. 1974. "Tractor and the Carabao: A Socio-Economic Study of Choice of Power Source for Land Preparation in Neuva Ecija." Paper presented at an International Rice Research Institute Saturday Seminar, Los Banos, Philippines, 27 July.

Berge, S. 1959. [New performance tests for North Swedish horses, at the State Agricultural Show at Jonkoping.] North Landbr. 17:459, 466. Taken from Anim. Breed. Abstr. 28:16; 1960 (Abstract no. 36).

Bhaid, M.U. 1975. Oil crisis and the bullock power on the farm. Agriculture and Agro-Industries J. 8:26-28.

Bhatia, R. 1976. Energy requirements of different farm systems; Rapporteur's Report. Ind. J. agric. Econ. 31(3):250-268.

Bhattacharya, P. 1959. "Investigations on standardization of draught capacity of bullocks in India." In Proceedings of the 7th International Congress of Animal Husbandry. Madrid, Spain. Vol. 8:141-143. International Congress of Animal Husbandry, 23 May-1 June.

Biddell, H. 1905. Heavy Horses. Breeds and Management, Fourth edition. Vinton and Company Ltd., London.

Bilik, K. 1974. [Investigations on the working ability and usefulness of Hutsul and draft type ponies for farm work in the Polish Carpathian region]. Acta Agraria et Silvestria Zootechnica, 14(1):27-49. Taken from Anim. Breed. Abstr. 43:111; 1975 (Abstract no. 927).

Binswanger, H.P. 1978. The Economics of Tractors in South Asia-An Analytical Review. Agricultural Development Council of New York and ICRISAT. Hyderabad, India.

Blaxter, K.L. 1962. Energy Metabolism of Ruminants. Charles C. Thomas, Springfield, Illinois.

Bloom, R.A. 1979. "A Review of Technical Evidence on the Use of Animal Traction in Sahelian Farming Sytems/" Ph.D dissertation, Michigan State University, East Lansing.

Boniface, J.J. 1903. The Cavalry Horse and His Pack. Hudson-Kimberly Pub. Co., Kansas City, Missouri.

Bostelmann, R.W. 1975. The management of sledge dogs in the Antartic. Polar Record. 18(112):25-35.

Bostelmann, R.W. 1976. Work with sledge dogs in the Antartic. J. Small Anim. Pract. 17:255-260.

Branch, D.S. 1978. Tools for Homesteaders, Gardeners and Small-Scale Farmers. Rodale Press, Emmaus, Pa.

Brockbank, R.B. 1971. Ox-drawn cultivation equipment. Bunda. Coll. Agric. Res. Bull. 2:57-59.

Brodell, A.P. and R.D. Jennings. 1944. Work performed and feed utilized by horses and mules. U.S.D.A. Bureau of Agric. Econ. Washington, D.C. June.

Brody, S. and R. Cunningham. 1936. Growth and development XL: Comparison between efficiency of horse, men and motor with special reference to size and monetary economy. Missouri Exp. Sta. Res. Bull. 244.

Brody, S. and E.A. Trowbridge. 1937. Efficiency of horses, men and motors. Missouri Exp. Sta. Res. Bull. 383.

Brody, W., H.H. Kibler and E.A. Trowbridge. 1943. Growth and development. LVII. Resting energy metabolism and pulmonary ventilation in growing horses. Missouri Agric. Exp. Sta. Res. Bull. 368.

Brody, S. 1945. Bioenergetics and Growth. Reinhold Co., New York.

Brzeski, E. and J. Morstin. 1963. [Studies on the utility value of mules]. Acta agrar. silvest., Ser zootech. [Kravkow]. 3:49-58. Taken from Anim. Breed. Abstr. 33:530; 1965 (Abstract no. 3125).

Budennyi, S.M. Editor [The book of the horse. Vol. 3] Moscow: Seljhozgiz., 1959. Taken from Anim. Breed. Abstr. 28:214; 1960 (Abstract no. 1086).

Buhle, P. 1934. [Evaluation of the pulling capacity of the horse.] Dtsch. landw. Tierz., 38:645-647. Taken from Anim. Breed. Abstr. 2:301; 1934.

Bulliet, R.W. 1975. The Camel and the Wheel. Harvard University Press, Cambridge, Mass.

Burgemeister, R. 1976. [Distribution and use of dromedaries (Camelus dromedarius).] Tropenlandwirt, 77:43-53. Taken from Anim. Breed. Abstr. 46:455; 1978 (Abstract no. 4067).

Campbell, J.K. 1973. Selecting field machinery. Cornell Agr. Eng. Ext. Bull. 395. Cornell University, Ithaca, New York.

Campbell, J.K. 1977. "Power for fieldwork." Department of Agricultural Engineering, Cornell University, Ithaca, New York (mimeographed).

Canadian Department of the Interior. 1922. Reindeer and Musk-Ox, Report of the Royal Commission. Department of the Interior. Ottawa, Canada.

Cardozo, A. 1965. Auquenidos. Editorial Universitaria. La Paz, Bolivia.

Carrington, R. 1958. Elephants. Chatto and Windus, London.

Castillo, L.S. 1967. "From Primitive to Modern Agriculture with Water Buffaloes." Paper presented at an International Agricultural Development Seminar, Cornell University, Ithaca, New York. May 24.

Cadambay, A.B. 1931. Plows and plowing: IV. Cost of plowing with different plowing outfits. Philippine Agriculturalist. 20:410-420.

Cerenpuncaq, S. and R. Davaa. 1967. [Camel breeding in Mongolia]. Mezhdunar sel.-khoz. Zh. 11(3):107-108. Taken from Anim. Breed. Abstr. 35:671; 1967 (Abstract no. 4009).

Chambers, W.H. and A.T. Milhorat. 1928. Muscular exercise and nitrogen metabolism of dogs. J. Biol. Chem. 77:603.

Chantalakhana, C. and S.R. Na Phuket. 1979. The role of swamp buffalo in small farm development and the need for breeding improvement in Southeast Asia. Asian and Pacific Council/Food and Fertilizer Technology Center Ext. Bull. 125.

Cockrill, W.R. . 1968. The draught buffalo (Babalus bubalis). The Veterinarian (Oxford), 5:265-272.

Cockrill, W.R. 1974. The Husbandry and Health of the Domestic Buffalo. FAO, Rome, Italy.

Cockrill, W.R. 1976. The Buffaloes of China. FAO. Rome, Italy.

Cole, H.H. and M. Ronning. 1974. Animal Agriculture. W.H. Freeman and Company, San Francisco.

Collins, E.V. and A.B. Caine. 1926. Testing draft horses. Iowa Exp. Sta. Bull. 240.

Consolazio, C.F., R.A. Nelson, L.O. Matoush, S.R. Harding and J.E. Canham. 1963. Nitrogen excretion in sweat and its relation to nitrogen balance requirements. J. Nutr. 79:399.

Coulomb, J. 1976. La race N'Dama, quelques caracteristiques zootechniques. Revue D'Elevage et de Medecine Veterinaire des pays Tropicaux. 29(4):367-380.

Crampton, E.W. 1964. Nutrient-to-caloric ratios in applied nutrition. J. Nutrition. 82:353-365.

Crampton, E.W. and L.E. Harris. 1969. Applied Animal Nutrition. W.H. Freeman and Co., San Francisco.

Cross, H.E. 1917. The Camel and Its Diseases. Bailliere, Tindall, and Cox, London.

Dalwig-Nolda, E.v. 1961. [Draft performance tests in horses]. Giessen, SchrReihe Tierz. Haustiergenet. 1:16-20. Taken from Anim. Breed. Abstr. 31:26; 1963 (Abstract no. 36).

Daly, H.W. 1901. Manual of Introduction in Pack Transportation. U.S. Military Academy, West Point, New York.

Dalzell, R. 1977. Buffaloes on oil palm estates in Malaysia. The Planter. 53(615):258-266.

Dennison, J.V., Jr. 1978. "Buffaloes vs Tractors: A Comparison of Their Use in Village Agriculture in Northern Thailand." Paper presented at a Departmental Seminar of Rural Sociology. Cornell University, Ithaca, New York. October.

Detkens, S. 1965. [The utilization of horses derived from the Ardennes breed and their draft efficiency]. Biul. Zakt. Hodow. doswiad. Zwierz. polsk. Akad. Nauk. 9:149-171. Taken from Anim. Breed. Abstr. 36:22; 1968 (Abstract no. 44).

Devadattam. D.S.K. and N.L. Maurya. 1978. Draftability of Hariana bullocks. Indian J. Dairy Sci. 31(2):120-127.

Devendra, C. and M. Burns. 1970. Goat Production in the Tropics. Technical Communication No. 9. Commonwealth Bureau of Animal Breeding and Genetics. Edinburgh. Commonwealth Agricultural Bureaux. Bucks, England.

deWilde, J.C. 1967. Experiences with agricultural development in tropical Africa. Vol. 1. The synthesis. Vol. 2. The case studies. Johns Hopkins Press, Baltimore, Md.

Dharmani, P.L.C., S.K.S. Lohara and N.A.A. Chohan. 1946. Feeding of farm animals. Indian Farming. 7(3):118-120.

Dill, D.B. 1936. The economy of muscular exercise. Physiol. Rev. 16(2):263-291.

Dobrev, D.G. 1967. [The performance of Arab horses in Bulgaria.] Nauchni Trud. vissh selskostop. Inst. Georgi Demitrov zootekh. Fak., 17:159-166. Taken from Anim. Breed. Abstr. 36:385; 1968 (Abstract no. 2265).

Duff, B. 1978. "The Potential for Mechanization in Small Farm Production Systems." Paper presented at the Bellagio Conference, 19-23 October. Rockefeller Foundation.

Dumic', A., and H. Korac'. 1963. [The performance of the domestic mule compared with the Bosnian Pony.] Vet. Glasn. 17:763-769. [Serb. cro.] Taken from Anim. Breed. Abstr. 32:137; 1964 (Abstract no. 804).

Dusek, J. 1961. [Performance tests with maximum loads for horses.] Zivocisna Vyroba. 6(34):571-588. Taken from Anim. Breed. Abstr. 30:17; 1962 (Abstract no. 49).

Ellis, G. 1972. "The Economics of Tractorization and the Dynamics of Growth in ADA District Ethiopia." Paper presented at the Annual Meeting of African Studies Association. Sheraton Hotel, Philadelphia, Pa.

Ellis, L.W. and E.A. Rumley. 1911. Power and the Plow. Double Day Page and Co., Garden City, New York.

Epstein, H. 1969. Domestic Animals of China. Morrison and Gibb Ltd., London and Edinburgh.

FAO. 1971. Tillage and Seeding Practices and Machines for Crop Production in Semi-Arid Areas. Agricultural Development Paper No. 92. FAO, Rome, Italy.

FAO. 1972. Employment of Draught Animals in Agriculture. FAO, Rome, Italy.

FAO. 1977. The Water Buffalo. FAO Animal Production and Health Series No. 4. FAO, Rome, Italy.

FAO. 1978. FAO Production Yearbook No. 32. FAO, Rome, Italy.

Fernandez-Baca, S. 1978. "Llamoids or new world camelidae." In: Animal Husbandry in the Tropics, pp. 499-518. By G. Williamson and W.J.A. Payne. Longman, London and New York.

Ferrier, A.J. 1947. The Care and Management of Elephants in Burma. Messrs. Steel Brothers and Co. Ltd., London.

Fisher, --. 1950. [Hafling horses under test.] Tierzuchter, 2:413-414. Taken from Anim. Breed. Abstr. 19:33; 1951 (Abstract no. 33).

Fischer, H. 1974. [The training and management of working elephants in Thailand.] Tierarztliche Umshau. 29(6):346-351. Taken from Anim. Breed. Abstr. 42:633-634; 1974 (Abstract no. 5543).

Forbes, W.H. 1945. The effects of hard physical work upon nutritional requirements. Milbank Mem. Fund. Quart., 23:89-96.

Forde, D.C. 1961. Habitat, Economy and Society. Methuen and Co. Ltd., London.

Foster, J. 1979. Training the Rott as a draught dog. Dog Sport. 1(8):32-33.

Fournier, A. 1973. [Animal traction in N. Cameroon. Achievements and prospects for the future.] Promotion Rur. 49:3-14. Taken from Abstr. Trop. Agric. 28:777; 1973 (Abstract no. w2592).

Garner, J.K. 1957. Increasing the work capacity of the water buffalo in drawing the plow and other drawn implements through the use of improved harness. United States Overseas Mission, Thailand. 1 October.

Gaury, Ch. 1962. La culture attelle et le material leger a traction animale. United Nations Conference for the Application of Science and Technology in the Interest of Developing Regions. Point de l'ordre du jour C.6.1/C.6.2. E/CONF. 39/C/374. 25 October.

Giuliani, R. 1961. [The future of work-meat cattle breeds.] Riv. Zootec. 34:392-399. Taken from Anim. Breed. Abstr. 30:485; 1962 (Abstract no. 2370).

Gopland, S. 1970. Bullock-drawn ground-nut digger. Indian Farming. 11(11):55-60.

Gopland, S. and S.E. Anantharaman. 1970. Bullock-drawn potato digger. Indian Farming. 11(11):36-37.

Great Britain. 1923. Animal management. Prepared in the Veterinary Department of the War Office. H.M. Stationary Office, London.

Gregoire, R. 1976. [Animal traction in the Sudan-Sahel zone.] Courrier (UN). 37:31-34. Taken from Abstr. Trop. Agric. 2:54; 1976 (Abstract no. 11150).

Groeneveld, B.J.B. 1960. [The performance testing of horses]. Tijdschr. 29:99-110. Taken from Anim. Breed. Abstr. 28:378; 1960 (Abstract no. 1786).

Grosev, S.G. 1952. [Testing draft horses and their crosses]. Konevodstvo. 22(3):36-41. Taken from Anim. Breed Abstr. 20:213; 1952 (Abstract no. 990).

Hall, W. and S. Brody. 1933. Growth and Development. XXVI. The energy increment of standing over lying and the energy cost of getting up and lying down in growing ruminants (cattle and sheep); comparison of pusle rate, respiration rate, tidal air, and minute volume of pulmonary ventilation during lying and standing. Missouri Exp. Sta. Res. Bull. 180.

Hall, W.C. and S. Brody. 1934. Growth and Development. XXXII. The energy cost of horizontal walking in cattle and horses of various ages and body weights. Missouri Exp. Sta. Res. Bull. 208.

Hamori, D. 1955. [Changes in stallions of saddle breeds during performance tests.] Magy. allatorv. Lapja. 10:58-64. Taken from Anim. Breed. Abstr. 24:12; 1956 (Abstract no. 38).

Hamori, D. 1964. [Comparative tests for determining maximum tractive force in Hungarian horse breeds.] Arch. Tierz. 7:63-75. Taken from Anim. Breed. Abstr. 33:33; 1965 (Abstract no. 45).

Harper, M.W. 1928. Horse breeding. Cornell Ext. Bull. 165. Cornell University, Ithaca, New York.

Haring, F., E. Wode and H.J. Hesse. 1956. [Pulling capacity of cows with respect to breed differences.] Mitt. dtsch. Landw-Ges. 71:533-536. Taken from Anim. Breed. Abstr. 24:335; 1956 (Abstract no. 1500).

Hart, E. Fl. 1976. The Golden Guinea Book of Heavy Horses, Past and Present. David and Charles, North Pomfret, Vermont.

Hattersley, M.C. 1951. Kenana cattle at the Gezira Research Farm. East African Agric. J. 17:27-31.

Herre, W. 1943. [The question of the cause of domestication phenomenon. Results of an expedition of the Schulz-Kampfhenkel Research Group.] Zool. Anz. 141:196-214. Taken from Anim. Breed. Abstr. 15:194; 1947.

Hesse, H.J. 1956. [Working ability and food requirements of small horses compared with large horses and cattle.] Tierzuchter. 8:160-163. Taken from Anim. Breed. Abstr. 24:229; 1956 (Abstract no. 961).

Heyer, J. 1975. A preliminary report on farm surveys: Tractor and ox cultivation in Makunei and Bungoma. In: Proceedings Of A Workshop On Farm Equipment Innovations For Agricultural Development And Rural Industrialization. Edited by S.B. Westley and B.F. Johnston. University of Nairobi, Institute of Development Studies Occasional Paper No. 16. Kabete.

Hill, A.V. 1927. Muscular Movement in Man. McGraw-Hill Book Co., New York.

Hill, O.C. 1976. Packing and outfitting field manual. Univ. Wyoming Agric. Ext. Serv. Bull. 636.

Hintz, H.F., S.J. Roberts, S.W. Sabin and H.F. Schryver. 1971. Energy requirements of light horses for various activities. J. Anim. Sci. 32:100-102.

Hoffman, L., W. Klippel and R. Schiemann. 1967. [Energy exchange in the horse with particular reference to horizontal movement.] Arch. Tierernahrung. 17:441-449. Taken from Nutr. Abstr. and Rev. 38:633; 1968 (Abstract no. 3604).

Holle, J. 1975. Le tracteur animal. Machinisime Agricole Tropical. CEEMAT (France) 51:46-56.

Honzawa, S., S. Ishizaki, A. Shinohara and K. Koyama. 1960. [Relation between body dimensions and work power in the horse (Relation between size and work power in the horse. V.).] J. Kanto-Tosan agric. Exp. Sta. Taken from Anim. Breed. Abstr. 28:378; 1960 (Abstract no. 1787).

Hopfen, H.J. 1969. Farm Implements for Arid and Tropical Regions. No. 91. FAO, Rome, Italy.

Horse and Mule Association of America, Inc. 19 . Collar, hames and harness fitting. Leaflet No. 276. Horse and Mule Association of America. Chicago, Illinois.

Horse and Mule Association of America, Inc. 1946. Horse and mule power in American agriculture. Book No. 288. Horse and Mule Association of America. Chicago, Illinois.

Huguenot, R. 1976. [Collection of oil palm bunches in a plantation. Use of ox carts.] Oliagineux (France). 31(10):423-426. Taken from Abstr. Trop. Agric. 3(3):126; 1977 (Abstract no. 13692).

Hulst, H. 1975. The role of farm mechanization in developing countries. In: Proceedings Of A Workshop On Farm Equipment Innovations For Agricultural Development And Rural Industrialization. Edited by S.B. Westley and B.F. Johnston. University of Nairobi, Institute of Development Studies Occasional Paper No. 16. Kabete.

Humbert, G. 1948. [Investigating the suitability of Black Pied Lowland cattle as draft animals.] Kuhn-Arch. 61:63-175. Taken from Anim. Breed. Abstr. 18:158-159; 1950 (Abstract no. 525).

Hussain, M.A. editor. 1964-65. *Annual Report; Ayub Agricultural Research Institute, Lyallpur*. Department of Agricultrue of the Government of Pakistan.

Hussain, M.A. editor. 1966-67. *Annual Report; Ayub Agricultural Research Institute, Lyallpur*. Department of Agriculture of the Government of Pakistan.

I.C.A.R. 1960. Definitions of the characteristics of cattle and buffalo breeds in India. Indian Council of Agricultural Research Bulletin Series 14. New Delhi, India.

I.C.A.R. 1966. *Handbook of Agriculture*. Edited by C.G.R. Kurup. Indian Council of Agricultural Research. New Delhi, India.

I.C.A.R. 1973. Definitions of characteristics of cattle and buffalo breeds. Indian Council of Agricultural Research Bulletin Series 86. New Delhi, India.

I.L.C.A. 1979. *Trypanotolerant Livestock in West and Central Africa*. Vol. 2. Country Studies. International Livestock Center for Africa, Addis Ababa, Ethiopia.

Iniguez, L. 1980. Personal communication. Cornell University, Ithaca, New York 14853.

Iorov, I. 1963. [Daily performance of horses of the Danube and Heavy Draft breeds used for agricultural work and transport.] Izv. Inst. Zivotn. "G. Dimitrov" Kostinbrod. 18:51-74. Taken from Anim. Breed. Abstr. 32:291; 1964 (Abstract no. 1780).

Iorov, I. 1969. [Estimation of traction power in some Bulgarian horse breeds.] Zhivotnovudstvo. 23(1):32-37. Taken from Anim. Breed. Abstr. 39:230; 1971 (Abstract no. 1413).

Ishizaki, S. and S. Honzawa. 1949. [Relation between size and working power in the horse. I. On the working power of Korean ponies.] Jap. J. zootech. Sci. 20:92-96. Taken from Anim. Breed. Abstr. 19:33; 1951 (Abstract no 34).

Ishizaki, S., S. Honzawa, A. Shinohara and K. Koyama. 1954. [Relation between body weight and work power in the horse. IV.] Jap. J. zootech. Sci. 25(2/4): 168-173. Taken from Anim. Breed. Abstr. 23:123; 1955 (Abstract no. 515).

Ishizaki, S., S. Honzawa, A. Shinohara and K. Koyama. 1961. [Comparison of the working ability of cattle and horses.] J. Kanto-Tosan agric. Exp. Sta. 18:259-268. Taken from Anim. Breed. Abstr. 30:314; 1962 (Abstract no. 1522).

Ishizaki, S., S. Honzawa, A. Shinohara and K. Koyama. 1961. [What size of working horse is necessary for deep ploughing? (Relationship between size and working ability in the horse. VI.)] J. Kanto-Tosan agric. Exp. Sta. 18:251-258. Taken from Anim. Breed. Abstr. 30:319; 1962 (Abstract no. 1560).

Ivanov, M.S. 1950. [A method of testing draft horses.] Konevodstvo. 1950(7):21-26. Taken from Anim. Breed. Abstr. 18:367; 1950 (Abstract no. 1245).

Ivanov, M.S. 1952. [The results of complex testing of Vladimir horses.] Konevodstvo. 22(4):33-40. Taken from Anim. Breed. Abstr. 20:213; 1952 (Abstract no. 991).

Iwema, S. 1960. [Th ship of the desert.] Veeteelten. Zuivelberichten. 3:390-394. Taken from Anim. Breed. Abstr. 30:98; 1962 (Abstract no. 496).

Johnson, H.D. and R.G. Yeck. 1964. Environmental physiology and shelter engineering. Missouri Exp. Sta. Res. Bull. 865.

Johnson, H.D. 1967. Climatic effects on physiology and productivity of cattle. In:*Ground Level Climatology*. Edited by R.H. Shaw. American Association for the Advancement of Science. Publication 86. Washington, D.C.

Johnson, L. 1964. Power equipment for rice production. In: *International Rice Research Institute Annual Report*. Los Banos, Philippines.

Jones, K. and E. Jones. 1976. *The Evener*. 1(1) April. Goshen, Massachusetts.

Jones, E. 1980. *The Evener*. 5(3):50 June/July. Putney, Vermont.

Jordan, W.H. 1905. *The Feeding of Farm Animals*. Third edition. Macmillan Co., London.

Joshi, N.R. and R.W. Phillips. 1953. *Zebu Cattle of India and Pakistan*. FAO Agricultural Series No. 19. FAO, Rome, Italy.

Joshi, N.R., E.A. McLaughlin and R.W. Phillips. 1957. *Types and Breeds of African Cattle*. FAO Agricultural Series No. 37. FAO, Rome, Italy.

Jurgenson, P.B. 1953. [The scientific laboratory at Taiga (The PechoraIlych State Reserve.)] Priroda [Mosk]. 42(8):62-66. Taken from Anim. Breed. Abstr. 22:362; 1954 (Abstract no. 1707).

Jurion, F. and J. Henry. 1969. *Can Primitive Farming Be Modernized?* Hors Serie (Translated from French by Agra Europe, London). Published with the assistance of the Belgian Co-operative and Development Office (O.C.D.) D/1969/0268/3.

Kallbrunner, H. 1941. [The influence on milk yield of using cows for draft purposes.] Dtsch. landw. Pr., 68(18):164. Taken from Dairy Sci. Abstr. 5:60; 1943 (Abstract no. 68).

Karlsen, G. 1963. [The sixth All-Union contests for draft horses.] Konevod Konnyi Sport. 33(9):26-28. Taken from Anim. Breed. Abstr. 32:138; 1964 (Abstract no. 808).

Keegan, T. 1974. The Heavy Horse: Its Harness and Harness Decoration. A.S. Barnes, Pelham, London.

Kehar, N.D., R. Mukherjee, V.V.S. Murty and K.C. Sen. 1943. Studies on protein metabolism, the effect of muscular work on endogenous protein catabolism in cattle. Indian J. Vet. Sci. 13:263-266.

Kellner, O. 1914. The Scientific Feeding of Animals (authorized translation by William Goodwin). Macmillan and Co. Ltd., Toronto, Canada.

Keuther, D.O. and B. Duff. 1979. "Energy requirements for alternative rice production systems in the tropics." Paper presented at the Annual Meeting of the Society of Automotive Engineers, Milwaukee, Wisconsin. September, 1979.

Khepar, S.D., M.P. Kaushal and A.K. Katyal. 1978. Animal-drawn lift irrigation pump. Indian Farming. 28(1):31.

Kiamco, L. and J. McMennamy. 1979. Reflection of the energy requirements of small rice farmers. Agricultural Mechanization in Asia. pp. 11-15. Spring.

Kibler, H.H. and S. Brody. 1943. Growth and development. LVII: An index of muscular-work capacity. Missouri Agric. Exp. Sta. Bull. 367.

King, F.H. 1907. Physics of Agriculture. Fourth edition. By author. Madison, Wisconsin.

Kleiber, M. 1947. Body size and metabolic rate. Physiol. Rev. 27(4): 511-541.

Kleisch, J. and U. Neuhaus. 1948. Die Eignung des Niederrungsrindes als Zugtier. Tiersucht. 2:10-14.

Klement, J. 1972. [Evaluating the performance of black Kladruby horses.] Bulletin Vyzkumna Stanice pro Chov Koni Slatinany 16:49-54. Taken from Anim. Breed. Abstr. 43:11; 1975 (Abstract no. 941).

Kline, C.K., D.A.G. Green, R.L. Donahue and B.A. Stout. 1969. Agricultural Mechanization in Equatorial Africa. Institute of International Agriculture Research Report No. 6. Michigan State University, East Lansing, Michigan.

Knoess, K. 1977. The camel as a meat and milk producer. World Anim. Rev. 22:39-44.

Knorre, E.P. 1959. [Experiment on domesticating elks in the Pechero-Ilychskii Game Reserve.] Ohrana prirody i ozelenenie. Moscow: N.P. p. 11-22. Taken from Anim. Breed. Abstr. 31:515-516; 1962 (Abstract no. 3126).

Knorre, E.P. 1969. [Behavioral changes in elk in the process of its domestication.] Trudy Mosk. Obshch. Ispyt. Prir. Otd. Biol. 35:13-20, 99. Taken from Anim. Breed. Abstr. 39:764; 1971 (Abstract no. 5123).

Kolacek, S. 1933. [The influence on milk yield in cows.] Arch. Tierernahrg, Tierzuchter 8:372-415. Taken from Anim. Breed. Abstr. 1:11; 1933.

Korzenev, M. 1955. [Legion- a record load move.] Konevodstvo. 25(11): 37-38. Taken from Anim. Breed. Abstr. 24:12; 1956 (Abstract no. 39).

Kownacki, M., H. Hoffmannowa and J. Piotrowski. 1962. [Preliminary investigations on some physiological indices facilitating the evaluation of performance in draft horses.] Roczn. Nauk. rol.,B. 79:393-401. Taken from Anim. Breed. Abstr. 31:457; 1963 (Abstract no. 2707).

Kownacki, M. 1962. [Investigations on the value of Polish Koniks for draft.] Roczn. Nauk. rol., B. 81:119-130. Taken from Anim. Breed. Abstr. 32:138; 1964 (Abstract no. 811).

Kownacki, M. 1965. [Changes in ability of horses to show maximum draft force.] Roczn. Nauk. rol. Ser. B. 85:313-322. Taken from Anim. Breed. Abstr. 34:324; 1966 (Abstract no. 1848).

Krasnikov, A. [S.], and V. [A.] Parfenov. 1964. [Tests of Kabarda horses.] Konevod. Konnyi. Sport. 34(7):8-12. Taken from Anim. Breed. Abstr. 33:33; 1965 (Abstract no. 48).

Krautforst, J.W. 1947. [Influence of work balanced by food on the efficiency of cows.] Przegl. hodowl, 15:122-219; 196-202. Taken from Anim. Breed. Abstr. 16:115; 1948 (Abstract no. 490).

Krendel, E.S. 1967. Power miscellany, man and animal-generated power. In: Marks' Standard Handbook for Mechanical Engineers. Seventh edition. Edited by T. Baumeister. McGraw-Hill Book Co. Inc., New York.

Kruger, L. and G. Seefeldt. 1955. [Determination of performance of large and small horses.] Z. Tier. ZuchlBiol., 64:175-190. Taken from Anim. Breed. Abstr. 23:123; 1955 (Abstract no. 516).

Kuklin, A.F. 1951. [Results of the evaluation of the Tuva draft (Upper-Yenisei) breed group of horse.] Konevodstvo. 7:8-14. Taken from Animal Breed. Abstr. 20:13; 1952 (Abstract no. 54).

Kulkarni, T.N. 1935. A short study of elephant. Indian Vet. J. 12(1):11-17.

Lall, H.K. 1949. The use of cows for work. Indian Farming. 10(7): 286-287.

Lander, P.E. 1949. The Feeding of Farm Animals in India. Macmillan and Co. Ltd., London.

Lantin, R.M. 1964. "Energy Expenditure and Capacity of the Philippines Work Carabao While Pulling Loads." M.S. dissertation, University of the Philippines at Los Banos.

Laurent, C.K. 1968. The use of bullocks for power on farms in Northern Nigeria. Bull. Rural Econ. Soc. 3(2):235-262.

Leese, A.S. 1927. A Treatise on the One-Humped Camel. Haynes, Stamford, England.

Lehrner, H. 1951. [Performance tests for heavy horses.] Wien. tierarztl. Mschr. 38:39-108. Taken from Anim. Breed. Abstr. 19:301; 1951 (Abstract no. 1042).

Lele, U. 1976. Tractors and ox plows in Africa. Development Digest. 14(1):56.

Leonard, A.G. 1894. The Camel. Longmans, Green and Company. London.

Lessiter, F. 1977. Horsepower. Reiman Publications, Milwaukee, Wisconsin.

Leue, G. 1971. [A review: First camel race in Europe in 1969 at the Cologne Horse Race Track from the veterinary-physiological, genetic and biochemical point of view.] Deutsche. Tierarztliche Wochenschriff. 78(18):500-503. Taken from Anim. Breed. Abstr. 41:39; 1973 (Abstract no. 396).

Leupold, J. 1968. [The camel - an important domestic animal of the subtropics.] Blue Book vet. Prof., 15. Frankfurt am Main: Abteilung Behring-Praparate, Farbwerke Hoechst AG. MarburgLahn: Behringwerke AG. Pp. 1-6. Taken from Anim. Breed. Abstr. 38:699; 1970 (Abstract no. 4205).

Lewis, J. 1975. The status of the ox-drawn plow in Dukolomba. In AID Program Evaluation Discussion Paper No. 6. The Sociology of Pastoralism and African Livestock Project. The studies division Office of Evaluation, Bureau of Program and Policy Coordination. May, 1979.

Lhoste, P. 1967. Comportement saisonnier du betail Zebu en Adamaova Camerounais. I. Etude des femelles adultes: Comparison de la race local aux metis demi-sang Brahma. Revue d'Elevage et de Medecine Veterinaire des Pays Tropicaux. 20:329-342.

Lhoste, P. and R. Dumas. 1972. Embouche intensive des Zebus de L'Adamaova. I. Comparison de differents systems d'alimentation. Revue d'Elevage et de Medecine Veterinaire des Pays Tropicaux. 25(2):259-276.

Lihacev, A.I. 1962. [The domestic use of the moose (Alces alces) and the direction of the work done to domesticate it.] Voprosy ohrany prirody Zapadnoi Sibiri. 3. Novosibirsk. p. 91-98. Taken from Anim. Breed. Abstr. 33:294; 1965 (Abstract no. 1648).

Link, P. 1946. *Alpaca, Llama, Vicuna, Guanaco*. Ferrari Brothers, Buenos Aires, Argentina.

Linton, R.G. and G. Williamson. 1943. *Animal Nutrition and Veterinary Dietetics*. Second edition. W. Green and Son Ltd., Edinburgh.

Liu, C.H. 1978. The preliminary results of crossbreeding of buffaloes in China. Mimeo note, Research Institute for Animal Science of Kwangsi, The People's Republic of China.

Lonka, T. 1946. [Estimating the pulling power of horses.] Valt. Maatalousk. Julk. No. 126. Taken from Nutr. Abstr. and Rev. 16:625; 1946/47 (Abstract no. 3127).

Low, D.L. 1853. *Domesticated Animals of the British Islands*. Longman, Brown, Green and Longmans, London.

Lus, Ja. Ja. 1936. [Yaks and their hybrids with cattle.] Domasnie Zivotyne Mongolii: 293-348. Taken from Anim. Breed. Abstr. 5:137-138; 1937.

McDowell, R.E., B.T. McDaniel and N.W. Hooven. 1958. "The relation of the Rhomboideus (Hump) Muscle in Zebu and European Type Cattle." Paper presented at the Annual Meeting of the American Society of Animal Production, Chicago, Illinois, 28-29 November.

McDowell, R.E. 1966. Problems of cattle production in tropical countries. Cornell International Agricultural Development Mimeograph No. 17. Cornell University, Ithaca, New York.

McDowell, R.E. 1969. Effective planning for expanding livestock production in developing countries. Cornell International Agricultural Development Mimeograph No. 32. Cornell University, Ithaca, New York.

McDowell, R.E. 1972. *Improvement of Livestock Production in Warm Climates*. W.H. Freeman and Company, San Francisco, California.

McDowell, R.E. 1976. Importance of ruminants of the world for non-food uses. Cornell International Agricultural Mimeo No. 52. Cornell University, Ithaca, New York.

McDowell, R.E. 1978. "Feed resources on small farms." Paper presented at a Seminar of Improvement of Farming Systems. Bamako, Mali, 20 February-1 March. Mimeograph.

McDowell, R.E. and P.E. Hildebrand. 1980. *Integrated Crop and Animal Production: Making the Most of Resources Available to Small Farms in Developing Countries*. A Bellagio Conference, October 18-23, 1978. Working Papers. The Rockefeller Foundation.

McInerney, J.P. and G.F. Donaldson. 1975. *The Consequences of Farm Tractors in Pakistan*. World Bank Staff Working Paper No. 210. World Bank, Washington, D.C. February.

McKnight, T.L. 1969. The Camel in Australia. Melbourne University Press, Melbourne, Australia.

MacPherson, G. and D. Jackson. 1976. Village technology in Tanzania. Development Digest 14(1):48.

Marinic, I. 1957. [The working efficiency of the Lipitsa horse in spring plowing. (Short version of thesis.)] Veterinaria, Sarajevo. 6:139-149. Taken from Nutr. Abstr. and Rev. 28:153; 1958 (Abstract no. 697).

Marks', S.L. 1951. Mechanical Engineer's Handbook, 5th edition. McGraw-Hill Book Company, Inc., New York. Pp. 1079-1080.

Marsh, G.P. 1856. The Camel; His Organization, Habits and Uses. Boston, Gould and Lincoln, New York.

Mason, I.L. 1974. Draft animals. In: Encyclopedia Britannica. Fifteenth edition. H.H. Benton, U.S.A.

Matharu, B.S. 1966. Camel care. Indian Farming. 16(7):19-22.

Mathieu, P. 1959. La traction bovine. Bulletin D'Information de Constitut National pour L'Etude Agronomique du Congo Belge. 4:231-238.

Matthews, M.D.P. and D.W.M. Pullen. 1975. Cultivation Trials with Ox-Drawn Implements Using N'Dama Cattle in The Gambia. Tropical Agricultural Engineering Information, Report Series; Overseas Department. National Institute of Agricultural Engineering, Silsoe, Bedford, England.

Mauring, H. 1959. [The Estonian horse and its importance in breeding Tori horses.] Konevodstvo. 29(9):17-20. Taken from Anim. Breed. Abstr. 28:17; 1960 (Abstract no. 37).

Maynard, L.A. and J.K. Loosli. 1969. Animal Nutrition, 6th ed. McGraw-Hill Book Co., New York.

Menon, R.G. and N.S.L. Srivastava. 1968. The I.I.S.R. bullock-drawn chemical applicator. Indian Farming. 18(1):27-29.

Menon, R.G. and N.S.L. Srivastava. 1970. The I.I.S.R. seedcum fertilizer drill. Indian Farming. 11(11):11-13.

Merrill, W.C. 1975. The Impact of Agricultural Mechanization on Employment and Food Production. U.S. A.I.D. Occasional Paper No. 1. Washington, D.C. September.

Meyer, [E]. 1951. [Breeding for performance in German draft horses.] Tierzuchter 3:256-258. Taken from Anim. Breed. Abstr. 19:425-426; 1951 (Abstract no. 1547).

Michal, V. 1959. [Performance tests for horses.] Sborn. vysoke Sk. Zemed. Lesnicke [Brno], A.(1/2):145-159. Taken from Anim. Breed. Abstr. 28:17, 1960 (Abstract no. 38).

Milne, A.H. 1955. The humps of East African cattle. Emp. J. Exp. Agric. 23:234-239.

Milosavljevic, S. and N. Sevkovic. 1954. [Working capacity of the Pester mountain horse.] Acta vet., Belgrade. 4(4):83-87. Taken from Nutr. Abstr. and Rev. 25:987; 1955 (Abstract no. 5177).

Mitchell, H.H. and J.H. Kruger. 1928. The effect of muscular work upon the endogenous catabolism of tissues. J. Biol. Chem. 76:55.

Moe, P.W., W.P. Flatt and H.F. Tyrrell. 1972. Net energy value of feeds for lactation. J. Anim. Sci. 55:945-958.

Moen, A.N. 1973. Wildlife Ecology. W.H. Freeman and Comapny, San Francisco, Calforinia.

Monnier, J. 1965. Contribution a l'etude de la traction bovine au Senegal. I. Machisime Agricole Tropicale. 10:3-25.

Monnier, J. 1965. Contribution a l'etude de la tracition bovine au Senegal. II. Machisime Agricole Tropicale. 11:15-27.

Morrison, F.B. 1947. Feeds and Feeding. 20th edition. Morrison Publishing Co.,Ithaca, New York.

Morrison, F.B. 1956. Feeds and Feeding. Morrison Publishing Co., Ithaca, New York.

Mukherjee, D.P., S. Dutta and P. Bhattacharya. 1961. Studies on the draught capacities of Hariana bullocks. Indian J. Vet. Sci. 31(1):39-50.

Nadal'jak, E.A. 1961a. [Gaseous exchange in horses in transport work at the walk and trot with different loads and rates of movement.] Trudy Vses. Inst. Konevodstvo. 23:228-245. Taken from Nutr. Abstr. and Rev. 32:463; 1962 (Abstract no. 2230).

Nadal'jak, E.A. 1961b. [Gaseous exchange and energy expenditure at rest and during different tasks by breeding stallions of heavy draught breeds.] Trudy Vses. Inst. Konevodstvo. 23:246-261. Taken from Nutr. Abstr. and Rev. 32:463; 1962 (Abstract no. 2231).

Nadal'jak, E.A. 1961c. [Effect of state of training on gaseous exchange and energy expenditure in horses of heavy draught breeds.] Trudy Vses. Inst. Konevodstvo. 23:263-274. Taken from Nutr. Abstr. and Rev. 32:463; 1962 (Abstract no. 2232).

Nanda, P.N. 1966. Management of camels. Indian Farming. 15(12):38-42.

Nangia, O.P., R.D. Rana, N. Singh and A. Ahmad. 1978. A note on draught capacity in castrated and entire male buffaloes as reflected in some blood constituents. Anim. Prod. 27(2):237-240.

National Academy of Sciences. 1966. The outlook for animal agriculture in Africa. Proceedings of Fifthteenth Annual Meeting. Agricultural Research Institute, Washington, D.C.

National Research Council. 1949. Recommended Nutrient Allowances for Domestic Animals. No. 6. Recommended Nutrient Allowances for Horses. A Report of the Committee on Animal Nutrition. National Research Council, Washington, D.C.

National Research Council. 1966. Nutrient Requirements of Domestic Animals. No. 6. Nutrient Requirements of Horses. Second Revised Ed. National Academy of Science - National Research Council, Washington, D.C.

National Research Council. 1973. Nutrient Requirements of Domestic Animals. No. 6. Nutrient Requirements of Horses. Third Revised Ed. National Academy of Science - National Research Council, Washington, D.C.

National Research Council. 1976. Nutrient Requirements of Domestic Animals. No. 4. Nutrient Requirements of Beef Cattle. Fifth Revised Ed. National Academy of Science - National Research Council, Washington, D.C.

National Research Council. 1978a. Nutrient Requirements of Domestic Animals. No. 3. Nutrient Requirements of Dairy Cattle. Fifth Revised Ed. National Academy of Science - National Research Council, Washington, D.C.

National Research Council. 1978b. Nutrient Requirements of Domestic Animals. No. 6. Nutrient Requirements of Horses. Fourth Revised Ed. National Academy of Science - National Research Council, Washington, D.C.

Newbold, D. and W.B.K. Shaw. 1928. An exploration in the South Libyan desert. Sudan Notes and Records. 11:103-194.

Nirmal, T.H. 1970. Pusa improved gatherer for uniform compaction of soil. Indian Farming. 11(11):52-53.

Nirmal, T.H. and P.L. Luthra. 1970. Pusa wooden plough toolbar increases scope three-fold. Indian Farming. 11(11):47-49.

Nolle, J. 1975. Le tracteur animal. Mach. Agric. Trop. 51:46-56.

Nolle, J. 1978. Thoughts of a designer of animal-drawn equipment. In: Tools for Homesteader, Gardener and Small-Scale Farmer. Edited by D.S. Branch, Rodale Press, Emmaus, Pa.

Nourrissat, P. 1965. Etudes et Travaux: La Traction Bovine au Senegal. Agronomic Trop. Paris. 20:823-853.

Odend'hal, S. 1971. Energetics of cattle in their environment. Human Ecology. 1(1):3-21.

Odend'hal, S. 1978. Past, present and future research on livestock in Bangladesh - with particular emphasis on draft power and mechanization. No. 49. The Ford Foundation, Dacca.

Okai, M. 1975. The development of ox cultivation practices in Uganda. East. Afr. J. Rur. Dev. (Uganda). 8(1-2):191-214.

Oni, S.A. 1975. The present stage and prospects of agricultural mechanization in Nigeria. Beitrage zur Tropsichen Landwirtschaft und Vetermarmedizin. 13(2):125-135.

Orev, Y. 1976. Improving single furrow animal ploughing in Botswana. World Crops. 28(6):252-253.

Orr, N.W.M. 1966. The feeding of sledge dogs on Antartica expeditions. British Journal of Nutrition. 20:1-12.

Oyenuga, V.A. 1967. Agriculture in Nigeria. FAO, Rome.

Peter, E.C. and C.V. Paul. 1965. A bullock-driven water-lift for deep wells. Indian Farming. 15(2):11-12.

Peter, W. 1963. [Performance tests of younger stallions at the Moritzburg State Stallion Depot.] Tierzucht. 17:174-176. Taken from Anim. Breed. Abstr. 31:458; 1963 (Abstract no. 2709).

Phillips, R.W., R.G. Johnson and R.T. Moyer. 1945. The Livestock of China. United States Government Printing Office, Washington, D.C.

Phillips, R.W., I.A. Tolstoy and R.G. Johnson. 1946. Yaks and yak-cattle hybrids in Asia. J. Heredity. 37(6):161-170.

Phillips, R.W., I.A. Tolstoy and R.G. Johnson. 1946. Yaks and yak-cattle hybrids in Asia. J. Heredity. 37(7):207-215.

Pino, N. 1947. [The variation in the lactose content of cow's milk before and after work.] Zootec. e. Vet. 2(7):233-35. Taken from Dairy Sci. Abstr. 12:140; 1950-51.

Pittet, P. and E. Schwab. 1969. The elephant theory. Ceres. No. 73. 13(1):40-44.

Plessard, F. 1974. [Study of a system to pump water by bovine traction.] Machinisime Agricole Tropical. CEEMAT (France) 47:44-52. Taken from Abstr. Trop. Agric. 1(6):107; 1975 (Abstract no. 7502830).

Plotnicki, J. 1954. [The tractive force in the principal types of horses in Poland.] Ann. Univ. M. Curie-Sklodowska, E. 9:263-277. Taken from Anim. Breed. Abstr. 24:229; 1956 (Abstract no. 962).

Podberezkin, Ja. 1951. [Experience of the work of a better camel breeding farm] Konevodstvo. 10:42-43. Taken from Anim. Breed. Abstr. 20:75; 1952 (Abstract no. 382).

Pogosjan, I.B. 1950. [Horses of the Kalinin and Stepanavan districts of the Armenian S.S.R..] Konevodstvo. 9:11-15. Taken from Anim. Breed. Abstr. 19:33; 1951 (Abstract no. 31).

Pool, T. 1940. [Results of work with Estonian Black Pied cattle in the breeding farm at Piistaoja.] Agronomia. 20:873-914. Taken from Anim. Breed. Abstr. 16:111; 1948 (Abstract no. 470).

Pradhan, S.N. 1970. Fertilizer drill for paddy. Indian Farming. 11(11): 15-16.

Prąwochenski, R. and W. Piotraszewski. 1955. [The pulling power of horses, based on tests carried out in 1951-52.] Med. vet. 11:20-23. Taken from Anim. Breed. Abstr. 23:254; 1955 (Abstact no. 1035).

Prigent, P. 1976. La traction animale. Guide de la Famille (France) ATEOS Paris (France). No. 75. 31 pp. Sept. Taken from Abstr. Trop. Agric. 4(2):95; 1978 (Abstract no. 18679).

Prigent, P. 1977. La cultre attelee. Guide de la Famille (France) ATEOS Paris (France). No. 79. 31 pp. May. Taken from Abstr. Trop. Agric. 4(2):89; 1978 (Abstract no. 18642).

Proctor, R.D., S. Brody, M.M. Jones and D.W. Chittenden. 1934. Growth and development XXXIII: Efficiency of work in horses of different ages and body weights. Missouri Exp. Sta. Res. Bull. 209.

Pruski, W. and M. Kownacki. 1962. [Investigations on the utility and working efficiency of horses of the agricultural type and those used for municipal transport. I.] Roczn. Nauk rol, B. 80:355-381. Taken from Anim. Breed. Abstr. 32:138; 1964 (Abstract no. 816).

Quibin, C.Q. 1951. The capacity of Philippine steers for plowing. The Philippine Agriculturalist. 34:155-162.

Raagaard, S. 1973. The tilling in a village in southern India. Geografisk Tidsskrift. 73:66-82.

Ragsdale, A.C., H.J. Thompson, D.M. Worstell and S. Brody. 1949. Environment physiology. Missouri Exp. Sta. Res. Bull. 449.

Ragsdale, A.C., H.J. Thompson, D.M. Worstell and S. Brody. 1950. Environmental physiology. Missouri Exp. Sta. Bull. 460.

Rajapurohit, A.R. 1979. Cross-breeding of Indian cattle: and evaluation. Economic and Political Weekly. 12(12-13):A9-A4.

Ramaswamy, N.S. 1978. "Notes towards the management of animal energy utilization in India." Vol. 1. Position paper No. 12. Indian Institute of Management, Bangalore, India, Mimeograph.

Ramaswamy, N.S. 1979. The modernization of the bullock cart system and the management of animal energy resources. Indian Institute of Management, Bangalore, India.

Ramiah, R.V., G.D. Chatterjee and T.S. Mukherjee. 1956. Hitch your moldboard plow right. Indian Farming. 6(4):28-30.

Rao, M.V.N. 1972. "A comparative study of the draft capacity of crossbred bullocks and indigenous bullocks." National Dairy Research Institute, Karnal, India. Mimeograph.

Rao, P.S. 1944. Comparative studies of some Indian ploughs with dynamometer. Indian J. Agric. Sci. 14(4):398-433.

Reid, J.R., A.M. Smith and M.J. Anderson. 1958. Difference in the requirements for maintenance of dairy cattle between pasture and barn-feeding conditions. *Proceedings of Cornell Nutr. Conf. for Feed Mfg., Buffalo, New York.*

Renaut, G. 1966. Contribution au developpment de la culture attelee en Cote D'ivoire. Machinisime Agricole Tropicale. 15:34-46.

Revelle, R. 1976. Energy use in rural India. Science. 192:4234-4246.

Rizwan-ul-Muqtadir, R.A.G., M. Ahmad and Z. Ahmad. 1975. Draught power and its effect on milk yield and milk composition in lactating buffaloes during winter season. Pakistn J. Agric. Sci. 12(1-2): 93-98.

Rollinson, D.H.L. and A.J. Nell. 1973. *The Present and Future Situation of Working Cattle and Buffalo in Indonesia.* UNDP/FAO Project INS/72/009 Supporting Livestock Planning. Working Paper. FAO, Rome, Italy.

Roth, M. and D. Norman. 1978. "Role of animals in the small farm enterprise." Paper presented at the Bellagio Conference, Italy, October 18-23.

Roy, S.R., A.K. Neogi and H. Guha. 1972. Cross-bred bullocks vs indigenous bullocks for draught purposes under West Bengal conditions. Indian Dairyman. 24:66-70.

Saghin, I., I, Maior and A. Popa. 1955. [Relative performance of draft (Ardennes), light-draft (F_1 trotter + Ardennes) and light horses, compared with that of Grey Steppe cattle.] Anal. Inst. Cerc. zooteh. 13:567-576. Taken from Anim. Breed. Abstr. 25:23; 1957 (Abstract no. 27).

Sargent, M.A. 1977. The use of animal traction techniques in the Kovande and Kerou Districts, Province de l'Atakore, Rep. Populaire du Benin: a Preliminary Report. Contract No. AID/afr-C-1260.

Sargent, M.A. 1979. "A village level extension guide for the introduction and maintenance of animal traction." Department of Agricultural Economics, Michigan State University, East Lansing, Michigan. October.

Sasimowski, E. and A. Wojcik. 1961. [Normal tractive force of Polish primitive horses.] Ann. Univ. M. Curie-Sklodowski, E. 14(1959):335-352. Taken from Anim. Breed. Abstr. 31:27; 1963 (Abstract no. 45).

Sasimowski, E. 1962a. [Comparative studies on the performance of Kopczyk Podlaski and Mur-Island horses, on the background of some physiological indices.] Ann. Univ. M. Curie-Sklodowski, E. 15(1960):203-220. Taken from Anim. Breed. Abstr. 31:27; 1963 (Abstract no. 44).

Sasimowski, E. 1962b. [A new method for testing the performance of horses. I. Investigations on draft performance tests of horses currently used in Poland and an outline of the author's own method. II. Investigations on the pulling power of state and licensed stallions using the author's own method.] Roczn. Nauk. rol., B. 79:135-165; 293-309. Taken from Anim. Breed. Abstr. 31:458; 1963 (Abstract no. 2711).

Sasimowski, E. 1963. [New method of estimating the strength and pulling power of horses. 2.Przegl. hodowl. 31(7/8):20-24. Taken from Anim. Breed. Abstr. 32:443; 1964 (Abstract no. 2701).

Sasimowski, E. 1976. [Performance testing of Polish horse breeds with regard to their different uses.] Leistungsprufungen von Sportpferden. 2. Internationales Wissenchaftliches Symposium (Vortrage). Leipzig, am 13. und 14. Juli. Leipzig, German Democratic Republic; Sektion Tierproduction und Veterinarmedzin der Karl-Marx-Universitat. 323-333. Taken from Anim. Breed. Abstr. 47:578; 1979 (Abstract no. 5293).

Sayer, W. 1934. Tests on Dunlop pneumatic equipment for farm carts, season 1933-34. Agriculture and Livestock in India. 4:524-533.

Schmidt, J., A. Mehner, W. Grabisch and H. Scherrbacher. 1952. Untersuchungen uber die Arbetisleistung von Fleckvienkuhen in Zuchtungskunde. 23:214-228.

Schmidt-Nielsen, K. 1964. Desert Animals: Physiological Problems of Heat and Water. Clarendon Press, Oxford, England.

Schneider, B.H. 1947. Feeds of the World, Their Digestibility and Composition. Agricultural Experiment Station, West Virginia University, Morgantown.

Schonmuth, G. 1957. [Position of draft performance tests in warm-blood horses and its signficance for breeding.] Tierzuchter. 11:54-56. Taken from Anim. Breed. Abstr. 26:20; 1958 (Abstract no. 44).

Schweisgut, O. 1957. [Determining the working performance of the Hafling breed.] Tierzuchter. 9:212-214. Taken from Anim. Breed. Abstr. 25:353; 1957 (Abstract no. 1682).

Scott, D. 1975. Animal power boosts new crop production. Appropriate Technology (UK). 2(1):7-9.

Scott, H.L. 1906. The skilled packer. U.S. Cavalry J. 1906-1907: 513-519. July.

SEAE/CEEMAT. 1972. Republique du Togo: Etude de l'evolution des facteurs de production mis en place pendant les 10 dernieres annees et de leurs effects. SEAE-CEEMAT. No. 534/M/72/S. November 28.

Sen, K.C. 1966. Nutritive values of Indian cattle feeds and the feeding of animals. Indian Council of Agric. Res. Bull. 25.

Shu, P.C., J.K. Lang, Y.C. Hus and S.Y. Chen. 1964. [Studies of the crossbreeds of Holstein and Syh-Yang cattle.] Acta. Vet. Zootech. Sinica: 7:23-32. Taken from Anim. Breed. Abstr. 33:365; 1965 (Abstract no. 2027).

Shulman, R. 1979. Strategy for the advancement of animal traction in Mali. U.S. A.I.D. au Mali en Liason avec le Division de Machinisime Agricole. Contract No. 688-79-514. June-October.

Singh, H. 1966. Domestic Animals. National Book Trust, New Delhi, India.

Singh, S.B. 1955. The elephant comes into farming. Indian Farming. 5(2):13-14.

Sitorus, P., M. Zulbardi and A. Roesyat. 1979. Performance of Bali cattle as work animals and milk and meat producers. Indonesian Agricultural Research and Development Journal. 1(1-2).

Sivenkova, N.V. 1959. [Results of testing the performance and pace of horses of different breed groups.] Trud. leningr. sel. hos. Inst. No. 14:98-103. Taken from Anim. Breed. Abstr. 28:378; 1960 (Abstract no. 1788).

Skulmowski, J. 1950. [Measuring tractive force in horses by means of a dynamometer.] Ann. Univ. M. Curie-Sklodowska D.D. 5:1-12. Taken from Anim. Breed. Abstr. 19:160-161; 1951 (Abstract no. 502).

Sleeper, J.A. 1978. "An Economic Analysis of the Role of Ox-Plowing and Cattle Feeding in the Stratification of West African Livestock Production." Master's Dissertation, Michigan State University, East Lansing, Michigan.

Slicher, Van Bath, B.H. 1963. (Translated by Olive Ordish.) The Agrarian History of Western Europe A.D. 500-1850. Edward Arnold Ltd. Publications, London.

Southworth, H. and M. Barnett. 1974. Experience in Farm Mechanization in South East Asia. Agricultural Development Council Inc., New York.

Spivak, T. 1976. [Testing draft breeds.] Konevodstvo i Konnyi Sport. 12:21-22. Taken from Anim. Breed. Abstr. 45:478; 1977 (Abstract no. 5207).

Srivastava, N.S.L. and R.G. Menon. 1970. The I.I.S.R. bullock-powered sprayer. Indian Farming. 11(11):23-24.

Steensberg, A., A. Fenton and G. Lerche. 1971. Tools and Tillage. GEC Gad Publishers, Copenhagen, Denmark.

Stillions, M.C. and W.E. Nelson. 1972. Digestible energy during maintenance of the light horse. J. Anim. Sci. 34:981-982.

Stout, B.A. 1966. Equipment for Rice Production. FAO Agricultural Development Paper, Rome, Italy.

Subrahmanyam, K.V. and J.G. Ryan. 1975. Livestock as a source of power in Indian agriculture: a brief review Occasional Paper No. 12. Economics Department, ICRISAT, Hyderabad 500-016, India, July.

Suciu, T., S. Romanovschi, E. Calinescu and M. Brumboiu. 1970. [First results obtained with a new semi-heavy type of horse for the Transylvanian lowlands.] Lucr. stiint. Inst. Cerc. zooteh. 27:467-479. Taken from Anim. Breed. Abstr. 39:437; 1971 (Abstract no. 2812).

Supekar, P.G. 1971. Yokegalls in draught animals. Farm J. (Calcutta) 12(8):23-24.

Swamy Rao, A.A. 1964. A report of the preliminary investigations, design and development testing and economic analysis of the new single and double bullock harness at the Allahabad Agricultural Implement and Power Development Center. Allahabad Agricultural Institute, May 1962-April 1964.

Syresin, I. and A. Dybin. 1955. [Performance testing of Vladimir draft horses.] Konevodstvo. 25(6):13-15. Taken from Anim. Breed. Abstr. 23:361; 1955 (Abstract no. 1585).

Tacher, G., F. Nicolas and P. Lachaux. 1969. Les bovins de culture attelee au Tchad. Machinisime Agricole Tropicale. 29:16-18.

Tatsumi, H., H. Chiba, M. Kato, K. Ueno, T. Okabe, Y. Seto and Y. Kano. 1958a. [Energy expense of horses in culture in a field.] Bull. Nat. Inst. Agric. Sci., Japan (Ser G). No. 14:81-91. Taken from Nutr. Abstr. and Rev. 29:146; 1959 (Abstract no. 689).

Tatsumi, H., H. Chiba and K. Ueno. 1958b. [Influence of the depth of water or energy expenditure of walking horses.] Bull. Nat. Inst. Agric. Sci., Japan [G]. No. 15:27-34. Taken from Nutr. Abstr. and Rev. 29:869; 1959 (Abstract no. 4100).

Tatsumi, H., H. Chiba and M. Kato. 1960. [Bioenergetical study on the drawing method of horses.] Bull. Nat. Inst. Agric. Sci.s, Japan [G]. No. 19:75-85. Taken from Nutr. Abstr. and Rev. 31:515; 1961 (Abstact no. 2437).

Taylor, R.J.F. 1957. The work output of sledge dogs. J. Physiol. (London). 137(2):210-217.

Telalbasic, R., B. Boskovic and B. Broz. 1973. [The pack-carrying capacity of the Bosnian Pony.] Stocarstvo. 27(3-4):123-127. Taken from Anim. Breed. Abstr. 41:595; 1973 (Abstract no. 5148).

Telleen, M. 1977. The Draft Horse Primer. Rodale Press, Emmaus, Pa.

Thierstein, G.E. and J. Kampen. 1978. "New farming systems for agriculture in the semi-arid tropics." Paper presented at the 1978 Summer Meeting of ASAE, Logan, Utah.

Tierzucht. 1949. [Science creates foundations for the promotion of further development of animal husbandry.] Tierzucht. 3:129-131. Taken from Anim. Beed. Abstr. 18:390; 1950 (Abstract no. 1339).

Tolaine, O. and P.J. Roston. 1957-58. Les animaux et l'effort de traction. Brazil (State) Divisao de mecanizacao agricola Boletim: 163-172, San Paulo, Brazil.

Tornede, H. 1939. [The problem of work performance of dairy cows with special reference to Red Hill cattle.] Zuchtungskunde. 14:308-333. Taken from Anim. Breed. Abstr. 8:230; 1954.

Turk, K.L. 1969. Livestock production in India. Cornell International Agricultural Development Reprint No. 31. Cornell University, Ithaca, New York.

Turk, Kenneth, L. 19 . "Other roles of animals, significance of animals in farming systems and in the provision of farm power and pleasure." Cornell University, Ithaca, New York. Mimeograph.

Ulinski, C. and A. Becker. 1976. IRRI designs of small scale farm equipment for deveoping country production. Development Digest. 14(1):62.

USDA. 1934. How to select a sound horse. Farmer's Bulletin No. 779.

USDA. 1938. Mule production. Farmer's Bulletin. No. 1341.

USDA 1949. Care and management of farm work horses. Farmer's Bulletin No. 1419.

U.S. War Department. 1944. Dog Transportation, FM25-6 War Department Field Manual. U.S. Government Printing Office, Washington, D.C.

Uzureau, C. 1974. Animal draft in West Africa. World Crops. 26:112-114.

Van Es, A.J.H. 1961. "Between-animal variation in the amount of energy required for the maintenance of cows." Ph.D. Dissertation. Laboratory of Physiology, Agricultural College, Wageningen, Netherlands.

van Leeuwen, A. 1952. The work capacity of horses for land cultivation compared with work capacity of cattle and buffalo. Hemera Zoa. Indonesian J. of Anim. Sci. 59:224-266.

VanSoest, P.J. 1981. Nutritional Ecology of the Ruminant. O and D Books, Corvallis, Oregon.

Varma, S.R. 1970. Bullock-drawn reaper for wheat harvesting. Indian Farming. 11(11):25-27.

Varma, S.R. and A.P. Bhatnagar. 1970. Bullock-drawn reaper with engine-operated cutting bar. Indian Farming. 11(11):29-31.

Vaugh, M. 1944. Report on a detailed study of methods of yoking bullocks for agricultural work. Paper presented to the Imperial Council of Agricultural Research. Indian J. Vet. Sci. Anim. Husb. 15:186-198.

Vaugh, M. 1947. A new traction dynamometer for the measurement of draft power of cattle. Allahabad Farmer. 21:77-78.

Vercoe, J.E. 1973. The energy cost of standing and lying in adult cattle. Br. J. Nutr. 30:207-210.

Viljcinskii, A.D. 1955. [Criss-cross breeding as an effective method of increasing the working quality of horses.] Konevodstvo. 25(1):11-14. Taken from Anim. Breed. Abstr. 24:125-126; 1956 (Abstract no.486).

Villegas, V. 1971. The role of work animals in the Philippines. Anim. Husb. Agric. J. 6(7):6.

Villers, G. 1976. The British Heavy Horse. Barrie and Jenkins. London.

Volkov, D. 1963. [Work performed by horses at studs in the Ukraine.] Konevod. konnyi Sport. 33(9):6-9. Taken from Anim. Breed. Abstr. 32:139; 1964 (Abstract no. 826).

Waldo, D.R., C.E. Coppock, L.A. Moore and J.F. Sykes. 1960. Estimates of the net energy maintenance requirement of grazing dairy cattle. In: Proceedings Fifth International Congress on Nutrition. Washington, D.C. September.

Washburn, R.S. and D. Merrick. 1936. Tillage, planting and harvesting equipment on grain farms and the rates of doing field work with these implements when drawn with horse and with tractor power. USDA Bureau of Agricultural Economics, Washington, D.C., December.

Watson, A. 1980. Personal communication. College of Veterinary Medicine, University of Florida, Gainesville, Fla., 32610.

Weatherley, Lee. 1978. Great horses of Britain. Spur Publications, Hindhead, Great Britain.

Weil, P. 1970. The ox plow in Central Gambia. In: African Food Production Systems, Cases and Theory. Edited by P.F.M. McLoughlin. John Hopkins Press, Baltimore, Maryland.

Whitlock, R. 1976. Gentle giants: the Past, Present and Future of the Heavy Horse. Lutterworth Press, Guildford, England.

Whyte, R.D. 1962. The myth of tropical grasslands. Tropical Agriculture. 34(1):1-11.

Williams, J.O. and E.B. Krantz. 1940. Care and management of farm work horses. Farmer's Bulletin No. 1419. USDA.

Williamson, G. and W.J.A. Payne. 1978. Animal Husbandry in the Tropics. Third Edition. Longman, Group Ltd., London.

Wilson, R.T. 1978. Studies on the livestock of Southern Darfur, Sudan. V. Notes on camels. Trop. Anim. Health Prod. 10(1):19-25.

Winchester, C.F. 1943. The energy cost of standing in horses. Science. 97(2505).

Wolff, E. 1875. Farm Foods (Translated by Cousins, H.H.). Gurney and Jackson,London, Great Britain.

Wooley, J.C. and M.M. Jones. 1925. The draft of farm wagons as affected by height of wheel and width of tire. Missouri Agric. Exp. Sta. Bull. 237:3-14.

Wrigley, G. 1971. Tropical Agriculture. Ebenezer Baylis and Son Ltd., Great Britain.

Yasin, S.A. and A. Wahid. 1957. [Pakistan camels - a preliminary survey.] Agric. Pakistan. 8:289-297. Taken from Anim. Breed. Abstr. 27:19; 1959 (Abstract no. 21).

Yousef, M.K., D.B. Dill and D.V. Freeland. 1972. Energetic cost of grade walking in man and burro, Equus asinus: desert and mountain. J. Applied Physiol. 33(3):337-340.

Zarikov, I.G. 1949. [Draft horses of Yaroslavl Province.] Konevodstvo. 5:12-16. Taken from Anim. Breed. Abstr. 18:20-21; 1950 (Abstract no. 32).

Zeuner, F.E. 1963. A History of Domesticated Animals. Hutchinson of London, Great Britain.

Zhigunov, P.S. 1961. Reindeer Husbandry, Second Edition. Zhurnalov i Plakatov, Moscow. [Translated from Russian by Israel Program for Scientific Translations, Jeruselum, 1968, for U.S. Department of the Interior and National Science Foundation, Washington, D.C. IPST Cat. No. 1901, 636.29, C28.].