Draught animal energy research in India

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Abstract

With the modernization of agriculture, the use of mechanical power in agriculture has increased but draught animal power (DAP) continues to be used on Indian farms due to small holdings and hill agriculture. More than 55% of the total cultivated area is still being managed by using draught animals as against about 20% by tractors. India possessed the finest breeds of draught animals. Bullocks, buffaloes and camels are the major draught animals for field operations. Horses, mules, donkeys, yak and mithun are the pack animals for transport. The quality of work from the draught animals depends upon the power developed by them. The design of traditional implements is based on long experience and these have served the purpose of the farmers. However there is plenty of scope to improve the design based on animal-machine-environment interaction so as to have more output and increased efficiency without jeopardizing animal health. This paper highlights some of the research related to DAP use in India.

Introduction

Information on draughtability on all the major Indian breeds of cattle, buffaloes and pack animals including cross breeds is scanty available. Major research programme has been undertaken on milch animals. Draught characteristics have been studied on limited breeds. Physiological norms for continuous working of animals without undue fatigue are not available. As a result animals are subjected to drudgery. Harnessing animals of different sizes or the use of double piece yokes for short and tall animals, and harnessing of different species of animals together is practised in few African countries but not in India. Animal carts vary in size in different regions. These require standardization and improvement to promote centralised manufacture of critical components. Equipment systems also need to be developed for operating stationary machines in rotary mode so as to increase the use of draught animals in a year.

Research gaps

- Draught animals in different regions vary greatly in sizes but matrix of distribution of weight is not available which helps in design of the farm machinery as per source of power available.
- The work-rest schedule practiced by the farmers is based on experience and convenience of operators. It needs to be developed on scientific lines to ensure minimum fatigue to the animal and operator. Also very little work has been done on physiology and nutrition of working animals.
- Out of 26 breeds of cattle and six breeds of buffaloes, draughtability studies on only four breeds have been done so far. The population of crossbred bullocks is increasing. No systematic studies have been done on draughtability of these bullocks for sustained working and scheduling of proper work-rest-cycles under different environmental conditions. About three million cows are used for draught work. No proper information on their draughtability is available.
- The annual utilization of draught animals is decreasing for which their use in rotary mode operation for agro-processing and other works during idle periods is to be increased. This would require an efficient rotary gear system for operating the machines.
- A large number of designs of animal carts are being used in the country. Their design details need to be standardized based on payload and terrain conditions. This may facilitate centralized manufacturing and interchangeability of parts and components.

With a view to increase the annual utilization and over all efficiency of draught animals, an ad-hoc project from Agricultural Produce fund in the name of *"Coordinated Research Programme on Increased Utilization of Animal Energy with Enhanced System Efficiency"* was started in January 1985 by the Indian Council of Agricultural Research (ICAR) at the Central Institute of Agricultural Engineering, Bhopal, India which was later converted into a regular all India coordinated research project from 1st July 1987. The major objectives of the scheme include:

- To study the draughtability characteristics of various draught animals in different regions and develop efficient matching equipment to increase the utilization of draught animals as source of farm power in crop production and post harvest operations without detrimental effect on the draught animals and the operators.

Specific objectives include:

i) To develop techniques and instrumentation for precise measurement of animal draught power in the field and laboratory and develop co-efficient of animal-equipment-terrain systems for their sustainable use.
ii) To study use of draught animals in agriculture including post harvest operations and identification of farm operations and equipment which required improvement and optimization of animal-equipment-terrain systems.
iii) To develop and evaluate efficient mechanical systems for use of animal power for rotary mode of applications like water lifting, threshing, winnowing etc.
iv) To design, develop and evaluate animal transport system for different regions.

Technical programmes

i) Development of an animal treadmill, animal loading car and studies on assessment of draughtability, work-rest-cycles and fatigue studies of selected breeds of animals.
ii) Package of implements for different cropping systems and agro-climatic regions.
iii) Development of system and equipment for use of draught animals in rotary mode for various agro-processing operations**.**
iv) Collection of data on DAP utilization, feeding, management and health care of animals.
v) Dissemination of technology.

Draught animals

Bullock and he- buffalo over three years of age are the main sources of draught animals for field operations. A small percentage of less than 2% of the total cows are also used in few eastern and southern states. Adult male and female camels are used for field operations and transport. Their population is estimated to be less than 1 %. It is observed that animals are of small size in many parts of the country, particularly in eastern part of India like Orissa, West Bengal, Assam and Bihar. The overall weighted average weight of the animals is 325 kg. The population of draught animals has declined to about 77.69 million in 1991-92 from 80.75 million in 1971-72 and is estimated as 77.13 million in 1996-97. The average DAP availability was estimated as 3.68 ha per pair.

Indian draught breeds: India possesses finest breeds of cattle for draught purposes. Systematic animal breeding programme exclusively for draught purpose is limited. The breeding programme on milch bovine has helped in producing good animals for draught purposes also. The cows of the draught breeds are poor milk yielders (1.5 -2.5 kg/day). Most famous draught breeds and their characteristics are described in Table 1 below:

Milch breeds: These are basically kept for milk. Milk yield ranges from 3.5-6.5 kg/day. The male progeny is reared and utilized as draught animals also. The characteristics are described in Table 2.

General utility breeds: These cattle are good for milk yield and their male progeny is excellent for draught purpose. Milk yield varies from 1.35 - 3.5 kg/day. The prominent breeds are listed in Table 3.

Buffaloes: In addition to bullocks, India also possesses very good he-buffaloes. Notable amongst these are listed in Table 4:

Table 1: Animal breeds and their characteristics.

Draught breeds	Draught characteristics	Area where can be found
Nagori	Fast and powerful.	Jodhpur region.
Hallikar	Strong, quick and steady, good for field and road power and endurance but fierce.	Mysore region.
Amritmehal		Mysore region.
Khillari	Hardy & fast, suitable for road and field.	Southern part of Maharashtra.
Bargur	Unsurpassable in hardiness & speed but difficult to train.	Coimbatore region.
Kangayam	Powerful and good for draught.	Coimbatore region.
Bachur	Medium draughtability.	Bhagalpur and Champaran in Bihar
Kankatha	Fairly powerful, suitable for light cultivation and road.	Banda, U.P. and Central India.
Kherigarh	Light draught and strutting.	Lakhmipur and Kheri region in UP.
Malvi	Good for road and field work.	Malwa Central India in Madhya Pradesh.
Panwar	Light ploughing having speed and stamina.	Pilibhit and Kheri in UP.
Siri	Useful for pulling carts.	Darjeeling, Sikkim and Bhutan.

Table 2: Milch breeds and their characteristics

Milch breeds	Draught characteristics	Area
Gir	Heavy and powerful but medium paced.	Kathiawar and Rajasthan.
Deoni	Good for heavy work.	North West region of Andhra Pradesh.
Red Sindhi	Useful for agricultural operations.	Assam, Orissa, Kerala and Madras region.
Sahiwal	Lethargic, useful for slow work.	Delhi, Punjab, UP and Bihar.

Table 3: General breeds and their characteristics

Breeds	Draught characteristics	Found in
Ongole	Powerful and suitable for heavy ploughing.	Nellore and Gunture in Andhra Pradesh.
Gaolao	Essentially draught breeds.	Chindwara, Wardha and Nagpur region.
Mewati	Docile, sturdy and steady in heavy ploughing, carting and water lifting.	Mathura, Alwar, Bharatpur and Kosi.
Nimariz	Docile and good at work lifting water.	Narmada Valley, Nimar and Khargaon regions of Madhya Pradesh.
Dangi	Slow but hardy.	Western Ghat of Maharashtra, Nasik, Thana, and Kolaba.
Hariana	Ploughing and road transport.	Haryana, Punjab and Rajasthan.
Rath	Admixture of Nagori, Hariana & Mewati. Moderate heavy field and roadwork.	Rajasthan.
Krishna Valley	For heavy ploughing but slow speed.	Krishna river of Bombay border and Hyderabad region.
Tharparker	Best dual-purpose breed. Suitable for field and carting.	Jodhpur, Jaisalmer.
Kankrej	Fast and powerful.	East of Rann of Kutch, Deesa, Radhenpur in Gujarat.

Table 4: Buffalo breeds and their characteristics

Buffalo breeds	Draught characteristics	Found in
Murrah	Medium draught , good for transport	Haryana and Uttar Pradesh
Bhadawari	Can stand heat better during field operations.	Agra, Etawah and Gwalior regions.
Jaffarabadi	Good for heavy draught.	Gir forests.
Nili-Rawi	Good for heavy draught.	Valleys of Sutlej and Ravi in Punjab.
Nagpuri	Slow in movement but good for heavy draught.	Nagpur region.

Research infrastructure

The research activities in the area of draught animal has been conducted at the Institutes of Indian Council of Agricultural Research (ICAR) mainly at National Dairy Research Institute, Karnal, Indian Veterinary Research Institute, Bareli, National Research Center on Camels, Directorate of Cattle, Modipuram and at Animal Husbandry Department of 26 State Agricultural Universities. Concerted research programme on draught animals was however, initiated by Central Institute of Agricultural Engineering, Bhopal sponsored by ICAR, New Delhi as an All India Coordinated Research Project on Increased Utilization of Animal Energy with Enhanced System Efficiency from 1st July, 1987. The coordinating unit is located at CIAE Bhopal. The project is being implemented at seven centres located at CIAE Bhopal, CTAE Udaipur, GBPUAT Pantnagar, AAI Allahabad, CAE Raichur, MKVP Parbani and AAU Jorhat. The cooperating centres are working on different types of animals as shown in Table 5.

Table 5: DAP research centres

Centre	Animals
CIAE, Bhopal	Malvi and local breed bullocks
GBPUAT Pantnagar	On buffaloes
CTAE, Udaipur	On camels and donkeys
AEC, Raichur	Khillari and donkeys
AAI Allahabad	Haryana and local breed bullocks
AAU Jorhat	Small animals of hill region
MKVP Parbani	Medium and heavy animals

Instrumentation system

The research on draught animals requires investigation on their fatigue parameters and resulting effect on power and energy produced. The fatigue can be measured through quantifiable and qualitative parameters (physiological) and performance indicator (speed and power). The scientists have developed instrumentation system and *score card index* to define degree of fatigue, which helps in taking out energy output from the draught animals without undue fatigue.

Tread mill: CIAE has a tread mill with associated instrumentation for simulated laboratories studies on draughtability, work-rest-cycle and fatigue for optimizing the work output of draught animals under different environment conditions. The tread mill has facilities for speed variation, draught loading and measuring devices and a 21x micro-logger with a Student physiograph for data storage and retrieval to study animal fatigue parameter -pulse rate, respiration rate and body temperature.

Loading car: The Institute has also a loading car, standard test track with instrumentation system and data logger for simultaneous measurement of heart rate, respiration rate, body temperature, power and energy for draughtability studies under metaled and farm road conditions. It exerts draught load in the range of 30-300 kgf and is a very useful and reliable equipment. The information generated through this instrumentation system is verified under field situations to predict the behavior of draught animals under actual field conditions in tillage, sowing, interculture and transport. The facilities are helpful to determine work-rest-cycles of draught animals . Studies have been undertaken to test the performance of yokes, harness and animal-implement system to standardize the design. Twelve units of CIAE animal loading cars were manufactured and supplied to the cooperating centres of UAE Scheme and to NRC on Camel, NDUAT Kumarganj, IGKVV Jagadalpur and NDRI Bangalore.

Fatigue scorecard: The draughtability experiments are usually conducted by varying the draught loads on animals and studying their effect on speed and fatigue levels under continuous work. The 'fatigue levels' of the animals have been defined by quantifiable parameters (body temperature, respiration rate, pulse rate and speed) and qualitative symptoms such as frothing, non-coordination of legs, excitement, inhibition of progressive movements and tongue protrusion. Based on the above fatigue parameters, Upadhyay & Madan (1985) derived score points to assess the draughtability of animals (Table 6). For oxen and buffaloes the maximum points were assigned 40 and for camels and donkey 30 and 32 respectively. The animal is considered fatigued at 40% of the maximum score points.

The limiting physiological response values (respiration rate, heart beat rate and body temperature) are given in Table 7 for selected draught animals. The initial values at rest R_o, H_o and T_o vary from animal to animal and the environmental conditions under which the animals are kept. The safe response values without getting the animal fatigued as reported by Upadhyay and Madan (1985) were R_0+30, H_0+20 and T_0+1.0 in the case of oxen. These measurable parameters contribute only 6 points from the total of 16 safe score points. In other words subjective parameters contribute more than quantifiable parameters and thus, this technique calls for further refinement of fatigue score card.

One of the major parameters, which effect the energy output of draught animal, is speed of operation. The speed is effected by continuous working with load. With continuous working in winter, the speed of animal was found to reduce, varying from 10-17% (Table 8). The speed is also affected by environment which has more pronounced effect than working load (Table 9). And therefore, environment effect on draughtability need to be studied with more seriousness and incorporated in the score card discussed above**.**

Table 6: Fatigue scoring for work oxen

Parameters	Score				
	1	**2**	**3**	**4**	**5**
Respiration rate/min	R_o +15	R_o + 30	R_o + 45	R_o + 60	R_o +75
Heart rate/min	H_o + 10	H_o + 20	H_o + 30	H_o + 40	H_o + 50
Rectal temp. (^oC)	T_o + 0.5	T_o + 1.0	T_o + 1.5	T_o + 2.0	T_o + 2.5
Frothing	First signs	Starts to dribble	Continuous dribbling	Froth on upper lips	Full mouth frothing
Leg coordination	Stride uneven	Occasional dragging of feet	Leg movement not coordinated frequent foot dragging	Complete loss of coordination in all legs	Unable to move
Excitement	Composed	Disturbed	Nostrils dilated, bad temper	Prominent eye ball movement	Furious and tying to stop
Inhibition of forward movement	Brisk	Free movement	Slow walking	Very slow	Stop walking
Tongue protrusion	Mouth closed	Occasional opening of mouth	Frequent appearance of tongue	Continuous appearance of tongue	Tongue fully out

Note: R_0, H_0 and T_0 are respiration rate, heart beat and body temperature values at rest .
Source : Upadhyay & Madan (1985)

Table 7: The range of fatigue parameters of draught animals

Animal	**Respiration rate** ***breath/min***	**Heart beat rate** ***beats/min***	**Body temperature** ***^oC***
Oxen	R_o + (15 - 75)	H_o + (10 - 50)	T_o + (0.5 + 2.5)
Buffaloes	R_o + (40 - 50)	H_o + (10 - 33)	T_o + (1.8 - 3.2)
Camel	R_o + (04 - 08)	H_o + (12 - 18)	T_o + (0.7 - 1.7)
Donkey	R_o + (15 - 50)	H_o + (15 + 45)	T_o + (1.0 - 3.0)

Source : Annual Reports of AICRPs on Utilization of Animal Energy. Central Institute of Agricultural Engineering, Bhopal.

Table 8: Effect of draught load on walking speed of a pair of oxen (local breed)

Draught, kg (% of body weight)	**Average speed of animals, km/h**				**Reduction in speed %**
	1st hour	2nd hour	3rd hour	4th hour	
63 (8)	3.26	2.99	2.83	2.71	16.9
80 (10)	3.12	2.90	2.85	2.66	14.7
95 (12)	2.80	2.71	2.56	2.50	10.7
110 (14)	2.63	2.45	2.43	2.27	13.7

Source : Gaur & Jain, 1993

Table 9: Effect of environment on speed of draught animals under no load condition

Animal	Speed of animal km/h		Reduction in speed %
	0800h	1600h	
Summer			
Crossbred	3.10	2.10	32
Malvi	3.35	2.30	31
Local	3.24	2.28	30
Winter			
Crossbred	3.22	2.15	33
Malvi	3.40	2.42	29
Local	3.28	2.32	29
Hot & humid			
Crossbred	2.98	2.52	15
Malvi	3.22	2.15	33
Local	3.12	2.15	31

Environment:

Summer : Temperature, 17-37 ^{0}C ; R.H., 15-57 %

Winter : Temperature, 7-24 ^{0}C ; R.H., 38-82 %

Hot & humid : Temperature, 15-35 ^{0}C ; R.H., 21-77 %

Significant research achievements

The Centers of the AICRP on UAE have made significant research contributions. These are briefly discussed below:

Draughtability studies

a) Non descript local breeds as well as Malvi, Nagori, Khillari and Haryana breeds of bullocks were able to exert draught, in sustained working conditions (7 to 8 hrs per day in 2 sessions), equivalent to 12% of their body weight during summer and winter seasons using local yoke. With improved 3-padded collar harness they were able to exert 14% load during summer and winter seasons.

b) He buffaloes were able to exert draught, in sustained working (of 6-7 hrs in 2 sessions) equivalent to 12% of their body weight using local Yoke in both summer and winter seasons.

c) Camels were able to exert draught load, in sustained working of 7-8 h in 2 sessions, equivalent to 18% the body weight. However following a work rest schedule of two-hour work and two-hour rest they could work for 8 hours at draught load equivalent to 26% of their body weight.

d) Donkeys were able to exert draught load, in sustained working of 6 h (in 2 sessions), equivalent to 32% of their body weight. However they could work up to 36% draught load for 4 h and 40% for 1 h.

e) Fatigue score cards for camels and donkeys have been developed which are being extensively evaluated.

Work rest schedule for animals

Based on the studies conducted at Udaipur, Rewari, Pantnagar, Allahabad and Raichur, the following work-rest schedule was found better from the work output point of view:

Bullocks

2 h work + 1 h rest + 2 h work + 1 h rest + 2 h work

3 h work + 1 h rest + 3 h work

4 h work + 2 h rest + 3 h work

Buffaloes

4 h work in the morning + 3 h rest + 4 h work in the evening

2 h work + 1 h rest + 2 h work + 1 h rest + 2 h work + 1 h rest + 2 h work in continuation.

Camels

2 h work + 1 h rest + 2 h work + 1 h rest + 2 h work + 1 h rest + 2 h work

Donkeys

1 h work + 1 h rest + 1 h work + h rest + 1 h work up to 6 h of work.

Package of implements

Improved yokes and harnesses

Allahabad type, 3 padded collar harness and Nagpuri yoke were tried on bullocks and buffaloes. Allahabad type harness was modified for lighter weight. Nagpuri wooden yoke gave 9-11% higher power output as compared to local yoke, in sustained working, both for bullocks and buffaloes Allahabad type single and double animal 3 padded collar harness gave 14- 25% higher power output as compared to local yoke, in sustained working, both for bullocks and buffaloes. These yokes and harnesses are now being popularized. Pantnagar centre developed adjustable yoke and collar harness for buffaloes which could be used for different row spacing. Harnesses for camels were also evaluated and Udaipur harness was found better than other harnesses. Study is continuing to develop improved harnessing system to use animals in multi-pairs.

Crop production equipment

Equipment package have been developed for tillage, sowing and weeding which gave higher area

coverage and lower cost of operation in comparison to existing size of implements. The increase in output obtained ranged from 30-70%.

Agro-processing machinery

Equipment have been developed for use of draught animals in rotary mode for various agro-processing operations like chaff cutting, flour grinding, soy flaking, grain cleaning, threshing, maize shelling and groundnut decorticating. The outputs obtained were as follows:

Flour grinder	8-25 kg/h
Soy flaking machine	23-25 kg/h
Grain Cleaner	200-450 kg/h
Paddy thresher	238-250 kg/h
Maize sheller	205 kg/h
Groundnut decorticator	100-150 kg/h
Chaff cutter	380-430 kg/h (green fodder)
	100-150 kg/h (dry fodder)
Paddy cleaner	710-1100 kg/h
Duplex reciprocating Pump	1800 l/h at 1m head

Load carrying capacity of pack animals

A study conducted at Udaipur showed that camels could carry a pack load of 50 kg continuously for 5 h, 150 kg for 3.5 h and 200 kg for 3 h sandy track while they can carry about 1600 kg in camel cart on sandy track and 2000 kg on tar macadam and kuchha roads. Studies conducted at Udaipur and Raichur centres showed that donkeys could carry a pack load 20-30 kg for 2-3 h, 50 kg for 2 h and 70 kg for 1 h while in a donkey cart they can pull load even up to 800-1000 kg on tar road.

Animal cart

A project has recently been started at CIAE Bhopal to standardize the design of bullock cart from the point of view of efficient working, centralised manufacturing of critical components and to use lighter materials.

DAP utilization

Yearly use of draught animals

Bench mark surveys on utilization of animal power in the selected villages in Bhopal, Ludhiana, Raichur, Pantnagar, Udaipur, Allahabad and Rewari have shown that the utilization of animal power in all these villages was low. In Bhopal, Allahabad Ludhiana and Raichur region mainly bullocks are used as draught animals while in Pantnagar region, both, bullocks and buffaloes are used. In Rewari and Udaipur regions camels and bullocks are used as draught animals. The average annual utilization of bullocks ranged from 281 to 828 h. Similarly, the annual use of camels in Udaipur and Rewari regions were 1220 and 499 h, respectively and buffaloes in Pantnagar region were 480 h.

Field operation of draught animals

In Bhopal, Raichur, Allahabad and Rewari regions bullocks were mainly used for tillage (66-88%), sowing (10-20%) and transport (11-14%) purposes. In Ludhiana region the bullocks were used mainly for transport of green fodder and other items and their use in this operation ranged from 69 to 98% by different categories of farmers. Bullock farmers used draught animal's time for 26% for tillage and 5% for sowing operations. In Rewari area utilization of camels were for about 44% for tillage, 18% for sowing and 38% for transport operations. Exclusively buffaloes were used in Pantnagar area for 86% for tillage, 5% for sowing, 8% for transport and less than 1% for other works.

The study showed that the draught animals in these regions are very much under utilized and they should be used for other jobs like agro-processing, water-lifting etc.

Cost of feeding and maintenance

Based on the studies conducted, the cost of feeding and maintenance of draught animals were as under at 1994 price level.

Bullocks	Rs. 38-40/pair/day
Buffaloes	Rs. 35-40/pair/day
Camels	Rs. 25-30/animal/day
Donkeys	Rs. 10-15/animal/day

Future research priorities

- Enhancing power availability from draught animals through draughtability studies and scheduling proper work rest-cycles.
- Enhancing output from draught animals by adoption of package of matching implements.
- Evaluation of animal transport system for different regions and improvement in the design of animal carts for centralised manufacturing of critical components.

Technical programme with respect to the thrust areas

- Studies on mechanics of animal traction under varying field and terrain conditions.

- Draughtability studies on new breeds of animals (bullocks, buffaloes and mules), crossbred bullocks and cows (in areas where they are used).
- Draughtability studies and work-rest-cycle for determination of coefficients for developing corelationship between draughtability of animals on treadmill, standard test track and under field conditions.
- Assessment of draughtability of animals in teamwork and development of proper harnessing system to be used by animals in teamwork.
- Evaluation of animal carts in different regions and standardization and improvement in the design of bullock carts for centralized manufacture of critical components.
- Use of pack animals for field operations.
- Collection of data on cost of feeding and management of animals (bullocks, buffaloes, camels, donkeys, mules etc.).

References

Anonymous 1960. Definition of the characteristics of cattle and buffalo breeds in India. ICAR Bulletin Series No.86, Indian Council of Agricultural Research, New Delhi.

Anonymous 1970. Wealth of India- Raw Materials, Vol. IV-Livestock. Publication and Information Directorate, Council for Scientific and Industrial Research, New Delhi.

Anonymous 1972, 1977, 1982 and 1987. Indian Livestock Census, Directorate of Economics and Statistics, Department of Agriculture & Cooperation, Ministry of Agriculture, Government of India.

Anonymous 1990. Annual Reports of All India Coordinated Research Projects on Utilization of Animal Energy in Agriculture, Indian Council of Agricultural Research, New Delhi.

Anonymous 1993. Report of the Technical Committee of Direction for Improvement of Animal Husbandry and Dairying Statistics, Department of Animal Husbandry & Dairying, Ministry of Agriculture, Government of India.

Gaur, K.N. & Jain, A.K. 1993. Performance comparison of modified Allahabad harness, Nagpuri yoke and Desi yoke. *Journal of Rural Energy* 2(2-4):80-88.

Khanna, N.D. & Rai, A.K. 1993. Camel draught power for rural energy, *Journal of Rural Energy* 2(2-4):33-41.

Kumar, A.S. & Swaminathan, K.R. 1993. Influence of age, breed and size on the draught capability of bullocks. *Journal of Rural Energy* 2(2-4): 42-52.

Maurya, N.L. 1982. Comparative study of crossbred and local bullocks. Proc. National Seminar on DAP System in India, Indian Institute of Management, Bangalore.

Maurya, N.L. & Devdattam, S.S.K. 1986. Draughtability of crossbred and local bullocks, *Indian Journal of Dairy Sciences* 39(3):337- 40.

Singh, G. 1994. Weight matrix of Indian cattle and their draught power. Indian Journal of Agricultural Engineering, 4 (3-4):100-106.

Srivastava, N.S.L. 1993. Status of research on engineering aspects of draught animal power, *Journal of Rural Energy* 2(2.4):15- 32.

Srivastava, N.S.L. & Ojha T.P. 1987. Utilization and Economics of Draught Animal Power. Technical Bulletin CIAE/ 87/51, Central Institute of Agricultural Engineering, Bhopal, India.

Upadhyay, R.C. & Madan, M.L. 1985. Draught performance of Hariana and crossbred bullocks in different regions. *Indian Journal of Animal Sciences* 55(1):50-54.

Upadhyay, R.C. & Madan, M.L. 1987. Work capacity, speed and efficiency of sustained work of crossbred and Haryana bullocks, *Indian Journal of Dairy Sciences* 40(1):28-41.

Upadhyay, R.C. 1993. Work- rest cycle for draught animals, *Journal of Rural Energy* 2(2-4): 58-67.