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Positive Environmental Externalities of Livestock in Mixed Farming Systems of India

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Abstract

Livestock are often criticized for their negative externalities to environment. However, in the mixed farming systems followed in India, the livestock help in saving natural resources through their synergistic relationship with cropping activities. This paper has quantified the positive environmental externalities associated with livestock production in India's mixed farming systems. These include: land saving due to recycling of agricultural by-products as animal feed and also due to use of dung- cake as domestic fuel; saving of chemical fertilizers due to use of dung as manure and prevention of carbon dioxide emission due to use of animal energy in agriculture. Land saving from livestock production system due to recycling of crop by-products as animal feed and use of dung as domestic fuel has been estimated as 42 Mha. The use of dung as manure saves 1.2 Mt of soil nutrients. Likewise, use of animal energy as a substitute for mechanical energy has potential to save diesel consumption to the extent of 13 Mt and prevents greenhouse gas emission due to burning of diesel.

Key words: Livestock, environment, mixed farming system, India

JEL Classification: Q51, Q20, Q0

Introduction

Livestock, despite their significant contributions towards enhancing food and nutritional security and reducing poverty, are often criticized for the negative externalities they cause to environment through emission of greenhouse gases, overgrazing/deforestation and water pollution (Steinfeld *et al.*, 2006). Impacts of livestock on environment, however, differ across production systems. Industrial livestock production systems cause more harm to environment, while mixed crop-livestock systems are benign to environment (Sere and Steinfeld, 1996). In the mixed farming systems, animals draw their energy requirements from environment in the form of feed from by-products of crops, from cultivated green fodder and from grazing, and in turn, give back that energy in the form of food (milk, meat, and eggs), draught power, fuel, and manure. With this process of energy exchange are associated a number of environmental externalities, negative as well as positive. Negative externalities of livestock to environment are well documented and quantified (Steinfeld *et al.*, 2006); but their positive contributions have remained less documented and non-quantified. The prominent positive environmental contributions include prevention of carbon di-oxide emission due to use of animal energy in place of fossil fuel, saving of natural resources mainly land as a result of recycling of agricultural by-products and residues as animal feed, and dung in place of firewood as domestic fuel and as a substitute for chemical fertilizers. Evidence also suggests that managed grazing helps in improving biodiversity (Pasha, 2005). In this paper, we have made an attempt to quantify some of the

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positive contributions of livestock to environment in India where livestock are largely raised in the mixed farming systems.

Analytical Approach

Information on feed consumption rates, by species, is an important requirement in estimating the positive environmental effects of livestock production. To our knowledge, there is little information available on feed consumption rates in India, except some localized information generated through surveys undertaken by the Indian Agricultural Statistics Research Institute (IASRI) during 1960s to early-1980s. This information is quite aged now and also there are problems in pooling of the data from surveys spread over such a long period.

In this paper, we have used data on feed consumption and several other attributes of livestock, viz. body size, grazing practices, dung production and its utilization, etc. from a nationally representative survey undertaken as part of a larger project, 'India's Livestock feed balance and its environmental implications', funded by the Indian Council of Agricultural Research (ICAR) under the National Agricultural Technology Project (NATP), and carried out jointly by the National Centre for Agricultural Economics and Policy Research (NCAP) and the Society (now Centre) for Economic and Social Research (SESR), Delhi. The survey was conducted in 2001-02 in different agro-climatic regions of India. A brief description of delineation of regions, survey design, data collection procedure, feed consumption estimation procedure and estimation of positive contributions of India's livestock production system have been given in the following sections.

Sampling Design

India has considerable heterogeneity in topography, soils, rainfall, irrigation, temperature, cropping pattern and livestock production systems. Hence, for any survey to qualify as a nationally representative sample, it must take into account this heterogeneity. To ensure that survey estimates were representative of the national situation, a multistage sampling framework was adopted to generate the required information. The National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) — an offshoot of the Indian Council of Agricultural Research, has mapped India's territorial space into 20 agro-ecological zones with their further classification into 60 sub-zones. However, for implementation of the survey, we have taken into consideration topography, climatic conditions and cropping pattern of 60 sub-zones, and re-organized these sub-zone into 11 broad regions, which we have termed as 'livestock regions'. In doing so, it was ensured that a livestock region was contiguous. These regions were: Western Himalayas, North-West Plains, Eastern Plains, Central Highlands, Eastern Plateau and Highlands, Deccan Plateau and Hills, Rajasthan-Gujarat Plains, Eastern Ghats, Western Ghats, Assam-Bengal Plains and North-Eastern Highlands.

The survey was conducted in 10 livestock regions, excluding North-Eastern Highlands. The stratified multistage random sampling approach was adopted in the study. From each livestock region, two districts (one from some regions) were selected at random; and from each selected district, two villages were selected again at random. A livestock census was conducted in each selected village to know the ownership pattern of different livestock species. Having enumerated livestock-keeping households, a random sample of 20-25 livestock-keeping households was drawn from each village to make up the total sample size of around 1000 households. Excluding the un-surveyed zone, we collected information from 864 households. The data were collected during the years 2001 and 2002.

Information related to the households and livestock holdings was collected from the heads of sample households. Information that required measurement, e.g. amount of different types of feed to be fed to different categories of animals by age-group, sex and function; and animal characteristics, e.g. body weight was generated by the field investigators at the household premises. Investigators were required to weigh and record the types of feed every day in the morning and evening, for complete one year to capture seasonality in feed consumption rates and their composition which was likely because of the seasonality in production of different types feed and also because of seasonal differences in the uses of livestock or their outputs. Considering that it was difficult to weigh and record different feeds every day, each household was revisited every fortnight for one year to collect this information.

Estimation of Feed Consumption Rates

Household level feed consumption rates serve as a base to estimate feed consumption rates at the national level. These rates were estimated applying scale-up factors at the levels of village, district and region. From the survey, we gathered information on (i) number of sample households having livestock, say buffalo in-milk and (ii) number of buffaloes in-milk observed, and (iii) amount of feed fed per day to these buffaloes in-milk. We then scaled-up information (ii) and (iii) to the successive higher levels, that is to village, district, region and country.

From the livestock census of each village, we had the total number of households having buffaloes in-milk. We obtained a scale-up factor for each village by dividing the total number of households having an animal species say 'buffaloe in-milk' by the number of sample households having buffaloes in-milk. We applied this factor to its sample estimates of (ii) and (iii) for each village.

Scaling-up factor for a district was obtained by dividing the total number of villages in that district by the number of sample villages from that district. Let us consider any of the sample districts in a region. For sample villages falling within it, we had already generated aggregate estimates of (ii) and (iii), respectively. We summed-up estimates of (ii) for the sample villages and multiplied this sum by the scale-up factor of that district to get district level aggregate of (ii). In the same way, we obtained district level aggregate of (iii). Likewise, we worked out aggregate estimates of (ii) and (iii) for the other sample districts in the region.

The scale-up factor for a region was obtained by dividing the number of districts in the region by the number of sample districts from that region. To obtain region-level aggregates of (ii) and (iii) we followed the same procedure as described for the district-level aggregation. The district-level estimates of (ii) for the sample districts were summed up; and this sum was multiplied by the scale-up factor to obtain the region-level estimates of (ii). Likewise, by multiplying the sum of (iii) by the scale-up factor, we obtained regional estimates of (iii).

Having estimated feed consumption rate for a livestock category at the regional level, the national level feed consumption rate was obtained as the weighted average of the regional feed consumption rates; the weight being region's population of that livestock category. The regional populations of different animal categories are aggregates of their district level populations for 2007 obtained from the 18th Livestock Census. The estimated consumption rates of different types of feeds and their total consumption are given in Table 1.

Quantification of Positive Externalities of Livestock to Environment

Land Saving due to Recycling of Crop Residues as Animal Feed

Using the feed consumption rates reported in Table 1, we quantified the positive contributions of India's livestock production systems to the environment following the 'Environmental Model of Livestock Production System' of Mishra and Dikshit (2004). The estimated positive effects included: resource (land) saving due to crop by-product recycled as animal feed, and due to use of dung as a domestic fuel; saving in chemical fertilizers due to dung-use as a manure; saving in fossil fuel (diesel) due to use of animal energy in agricultural operations. The model has been described below.

The gross energy intake per animal per day from by-product feed was estimated by summing up the energy values of by-product feed on dry matter basis. Similarly, the energy value of green fodder fed to the animals was also calculated on dry matter basis. Then, the annual quantity of green fodder required, in terms of energy to replace gross energy from by-product feed, was estimated as per Equation (1):

$$G_f = \left[\frac{1}{e} \times gei \times \frac{1}{d} \right] \times 365 \qquad \ldots(1)$$

where, *Gf* is the quantity of green fodder required to replace the by-product feed, *gei* is the gross energy intake from by-product feed (dry fodder and concentrates), *e* stands for the energy (million calories) per unit of *Gf;* and *d* is the dry matter fraction of green fodder. We then estimated the land area required to produce *Gf.* Let *y* be the yield of green fodder per hectare of land, then the area L required to produce *Gf* may be given by Equation (2):

Table 1. Feed consumption rates and dung evacuation rates, 2001-02

Livestock category	Type of feed consumed (kg/animal/ day)			Dry matter intake per animal per day (kg)	Gross energy intake, animal per day (MJ)	Wet dung production per animal per day (kg)
	Green fodder*	Dry fodder	Concentrates			
Cattle						
In-milk	4.75	5.50	0.64	7.01	108.44	6.63
Dry	3.40	4.02	0.40	5.15	77.82	6.58
Adult male	4.06	6.03	0.33	7.51	107.56	4.46
Young stock	2.18	2.13	0.18	3.07	42.42	4.43
Buffalo						
In-milk	5.96	6.34	1.05	8.88	132.34	8.35
Dry	5.44	4.95	0.52	7.35	101.96	8.49
Adult male	4.04	7.47	0.36	8.83	127.95	6.65
Young stock	2.29	2.22	0.19	3.69	44.33	4.43
Goat	1.50	0.20	0.06	0.61	10.58	0.30
Sheep	1.66	0.20	0.04	0.63	10.97	0.80
Others**	15.62	6.72	0.49	10.39	172.37	6.10

Notes: * includes grazing also
** includes horses and camels

$$L = \frac{G_f}{y} \qquad \ldots(2)$$

Land Saving due to Use of Dung as Substitute for Fire-wood in Domestic Fuel

In rural households, fire-wood is used as a domestic fuel; for cultivation or perennial fire-wood trees cover land and deprive its use for farming. The use of dung-cake as fire-wood would result in the saving of this land, which can be used for crop-cultivation. We, therefore, estimated the land saved due to use of dung cake as a domestic fuel. The dung-cake output on dry matter basis was worked out using dung evacuation rate and its dry matter fraction. Supposing δ as the rate of substitution of dry fuel-wood for dung cake (fuel-wood: dry dung cake) in terms of thermal energy, the total quantity of dry fuel-wood required to replace the supply (output) of dung cake was calculated by Equation (3):

$$Fw = \delta \times dc \qquad \ldots(3)$$

where, Fw is the quantity of fuel-wood required to replace dung cake, and dc is the quantity of dung cake output. Now, let us suppose that fuel-wood is produced and used within the year, and its yield per hectare on dry matter basis is y, then the total land area that would be required for producing Fw can be calculated by Equation (4):

$$\mathrm{L} = \frac{1}{y} \times Fw \qquad \ldots(4)$$

The effect of gestation lag in the production of fuel-wood can be described as follows: The model assumes that fuel-wood is produced and used within the same year. This is apparently an unrealistic assumption. In reality, more than one year is required to cover the whole process of fuel-wood tree plantation, growth and logging of trees, drying and use of cut-out wood as fuel. Suppose it takes 3 years to complete the process before dry wood is made available for use at the end of the 3rd or the beginning of 4th year. This means that whereas the fuel wood made available can replace equivalent amount of dung cake only in the fourth year, the necessary land area required for growing and harvesting of trees for making the fuel-wood available will have to be kept locked up during the preceding 3 years. This implies that around 3-times as much land will be required or saved if one year's dung cake output was used in place of fuel wood as energy source.

Saving of Chemical Fertilizers due to Use of Dung as Manure

The extent to which dung manure substitutes the chemical fertilizers, is a saving of chemical fertilizers. Fresh cattle dung on an average contains 0.30-0.40 per cent nitrogen (N), 0.10-0.20 per cent phosphorus (P_2O_5), and 0.10-0.30 per cent potassium oxide (K_2O) (Anonymous, 1997). According to the recent estimates of Ghosh *et al*. (2004), dung manure contains 0.71 per cent N, 0.18 per cent P_2O_5 and 0.71 per cent K_2O. In this study, we have used the fraction of soil nutrients (N,P and K) in dung-manure as estimated by Ghosh *et al*. (2004), and the total quantity of N, P and K was worked out for the proportion of bovine dung used as manure.

Saving of Fossil Fuel due to Animal Energy-use in Agriculture

If the working animals were to be replaced by agricultural machinery, it would require additional fuel and lead to emission of CO_2 from burning of the fossil-fuel. It is this emission that is prevented by the livestock. It has been assumed in the study that tractors are the only machine used and are of similar power; and also the working animals do not differ in their work capacity.

In order to determine the saving of fossil fuel and prevention of greenhouse gasses due to animal energy use, we need to know (i) the rate of substitution between tractors and working animals, (ii) the amount of diesel required for running a tractor to perform agricultural operations, and (iii) the amount of CO_2 that will be emitted from the burning of a unit of diesel. On the basis of economic substitution rate, 10 working males are required to replace a tractor. The number of tractors required for replacing country's bovine working stock, diesel use, and the associated emission of greenhouse gasses have been estimated.

Results and Discussion

India has one of the largest livestock populations in the world, and therefore its livestock sector has come under critical scrutiny of the international environmental monitoring agencies such as IPCC. According to the estimates of the Indian Network for Climate Change Assessment, the agricultural sector emitted 334 Mt of CO_2 in 2007, to which livestock contributed about 63 per cent. A number of studies in the past have quantified methane emission from livestock production. These studies have shown wide variations, ranging from 8.5 Mt to 10.5 Mt, depending on the methods and data used and also the year for which the gas emission was estimated (Lerner *et al*., 1988; Ahuja, 1990; Bhattacharya and Mitra, 1998; Mishra and Dikshit, 2004; Singhal *et al*., 2005; Swamy and Bhattacharya, 2006; Singh *et al*., 2012).

Notwithstanding their negative externalities, livestock in the mixed farming systems also help conserve natural resources and improve quality of environment. The estimates of the positive contributions of livestock to the environment are discussed below:

Land Saving due to Recycling of Crop Residues as Animal Feed

Livestock production in the mixed farming systems saves land by utilizing or recycling crop by-products, viz. dry fodder and concentrates as animal feed. If the by-product feeds were to be replaced by feed grains or cultivated green fodder, vast additional land will be required to produce that much feed and fodder. This land saving is a positive environmental effect. The problem here can be posed as follows. How much cultivated green fodder or feedgrains will be required if the gross energy intake of the ruminant population made available from the by-product feed, concentrates and dry fodder, were to be replaced by the energy from either of the former feeds. We have considered cultivated green fodder as the alternative source of feed energy.

The gross energy intake by the ruminant population from by-product feed was estimated by summing-up the energy values of the by-product feed on dry matter basis. Similarly, the energy value of green fodder fed to the animals was also calculated on dry matter basis. The energy value of dry fodder and feed concentrate (on dry matter basis) is 3.69 Mcal/kg and 4.38 Mcal/kg of feed. Using feed consumption rates given in Table 1, we have estimated that the by-product feed provides 169 million calories of energy per day to livestock. If this much energy were to be obtained from the cultivated fodder, India would require 1701 million tonnes of green fodder annually, and with an average fodder yield of 42.5 t/ha, the total area required to

Table 2. Land saving due to use of crop by-products as animal feed

Parameters	Parameter value	Source
Energy value of by-product feed on dry matter basis (Mcal/kg)		Krishna *et al*. (1978)
Dry fodder	3.69	
Concentrate	4.38	
Consumption of by-product feed and crop residues in terms of energy (Mcal)	168.8	Estimated by authors
Green fodder to dry matter ratio	1.0:0.25	Sen *et al*. (1978)
Yield of green fodder (t/ha)	42.5	Anonymous (1997)
Total green fodder required to replace by-products feed (Mt)	1701	Estimated by authors
Land area required to produce substituted quantity of green fodder (Mha)	40.0	Estimated by authors

produce this amount of fodder would be as large as 40 million hectares (Table 2).

Land Saving due to Use of Dung as a Substitute for Fire-wood in Domestic Fuel

Another way that livestock production saves land is through supplying of dung as a domestic fuel. Of the total wet dung produced (635 Mt), about 37 per cent (235 Mt) is used as domestic fuel. Considering 80 per cent moisture in the fresh dung, the total dry dung-cake production was estimated to be 47 Mt. At a replacement rate of 3.54 in terms of thermal energy, if this amount of dung-cake were to be replaced by fuel wood, India will require 13 Mt of fuel wood in addition to whatever quantity is produced otherwise. To produce this much amount of fuel wood, about 1.62 Mha of land will have to be constantly put to cultivation of fuel wood plants with 4.5 years of gestation lag (Table 3).

Saving of Chemical Fertilizers due to Use of Dung as Manure

After meeting its demand as fuel, the remaining dung is used as manure to fertilize crops, which indicates the savings in use of chemical fertilizers. About 76 Mt of dung (on dry matter basis) is used as manure. The total availability of soil nutrients from manure was worked out to be of 1.22 Mt comprising 0.54 Mt of N, 0.14 Mt of P and 0.54 Mt of K; it is equivalent to about 6 per cent of the total nutrients used in the country in 2007. These nutrients from manure can replace 2.63 Mt of ammonium sulphate,

Table 3. Parameter values for land saving due to use of dung cake as domestic fuel: 2007

Parameters	Parameter values	Source
Production of wet dung (Mt)*	635.0	Estimated by authors
Utilized as domestic fuel (%)	37	CSO, GoI (1996)
Proportion of moisture in wet dung (%)	80	Flote (2011)
Fuel wood yield (t/ha)	36.8	Chaturvedi (1993)
Replacement rate of fuel wood for dung cake in terms of thermal energy	1:3.54	KVIC (1983)
Gestation lag between planting and harvesting of fuel wood saplings /trees (years)	4.5	GoO (2007)
Production of dung cake (Mt)	46.99	Estimated by authors
Fuel wood required to replace dung cake (Mt)	13.3	
Land required to produce fuel wood :		
With 1 year gestation lag (Mha)	0.36	
With 4.5 year gestation lag (Mha)	1.62	

*Bovine dung production

Table 4. Saving of chemical fertilizers due to use of dung as manure: 2007

Parameters	Parameter values	Source
Proportion of wet dung utilized as manure (%)	60	CSO, GoI (1996)
Proportion of moisture in wet dung (%)	80	Flote (2011)
Fraction of plant nutrients in dung manure		Ghosh *et al*. (2004)
Nitrogen	0.0071	
Phosphorus	0.0018	
Potash	0.0071	
Fraction of N, P and K in chemical fertilizers		
Ammonium sulphate (N)	0.206	www.indiaagronet.com
Super phosphate (P)	0.444	
Murate of potash (K)	0.660	
Production of wet dung (Mt)	635.0	Estimated by authors
Dung Utilized as manure (Mt)	381.0	
Dung manure on dry matter basis (Mt)	76.2	
Saving of soil nutrients (Mt)		
Nitrogen (N)	0.541	
Phosphorus (P)	0.137	
Potash (K)	0.541	
Total (N, P & K)	1.219	
Saving of chemical fertilizers (Mt)		
Ammonium sulphate	2.63	
Super phosphate	0.31	
Murate of Potash	0.82	

0.31 Mt of super phosphate and 0.82 Mt of murate of Potash (Table 4). The available amount of these nutrients is apparently small, but its value in monetary terms could be substantial. Further, its environmental value can be gauged if we consider the associated emission in the production and transportation of the equivalent amount of chemical fertilizers at the farm-gate.

Saving of Fossil Fuel due to Use of Animal Energy in Agriculture

To estimate the contribution of animals towards saving of fossil fuel we need (i) substitution or replacement rate between working animals and tractors, and (ii) fossil-fuel (diesel) required per tractor per year to do the work of replaced animals. On an average, a bullock is rated at 0.4-0.5 HP (horse power). A 35 HP tractor is, therefore, supposed to replace at least 70 bullocks. It is a purely engineering rate of substitution between working animals and tractors. Some farm-level studies carried out during 1970s and 1980s in the north-western states of Punjab, Haryana and western Uttar Pradesh — the sheet of green revolution in India — have reported the replacement rates of three to four bullocks per tractor (Binswanger 1978; Sharma 1987; Mishra and Sharma 1990). Dikshit and Birthal (2010a;b) using time series data on the number of bullocks and tractors have arrived at a substitution rate of 10, that is, a tractor can replace 10 working animals. We have used this rate of substitution, and accordingly the country will require 5.5 million tractors to replace 55 million working animals. To use the services of required number of tractor stock, approximately 13.13 Mt of diesel would be required annually. Burning of diesel will emit about 4.17 Mt of carbon di-oxide or 0.2 Mt of methane, which is the methane emission prevented by the working animals.

Conclusions

Livestock have been singled out as one of the largest sources of methane emission after rice. Nevertheless, livestock also help conserve natural

Table 5. Quantity of diesel saved due to use of animal energy: 2007

Parameter	Parameter values	Source
Number of draught animals (millions)	55	GoI (2007)
Replacement rate	10.0	Dikshit and Birthal (2010)
Number of tractors required to replace existing stock of working animals (millions)	5.463	Estimated by authors
Number of operating hours (hours/year)	801	Stephane *et al*. (2009)
Consumption of diesel by required No. of tractors (Mt)	13.13	Mishra and Dikshit (2004)
Total carbon released from burning of estimated diesel use (Mt)	11.38	Estimated by authors
Emission of carbon dioxide prevented (Mt)	4.17	
Emission prevention equivalent to methane (Mt)	0.198	IPCC (1995)

resources, particularly in the mixed farming systems where there is a considerable synergy between crop and livestock activities. In this paper, we have identified and quantified the positive environmental contributions of livestock production system. Some of the positive contributions identified include: saving of land due to recycling of agricultural by-products as animal feed and also due to use of dung-cake as domestic fuel; saving in use of chemical fertilizers due to use of dung as manure; and prevention of carbon dioxide emission due to use of animal energy in Indian agriculture.

The study has found that there is enormous saving of land in the mixed farming system on account of use of agricultural by-products as feed and use of dung as domestic fuel. If the by-product feed were to be replaced by green fodder, as much as 1701 Mt of green fodder will be required to supply the equivalent amount of energy. To produce the required amount of green fodder, about 40 Mha of land will be needed. Further, to replace the quantity of dung –cake used as domestic fuel by fuel wood, the required amount of fuel wood in terms of thermal energy would be 13.3 Mt. The land resource required with three year of gestation lag would be 1.62 Mha. The total land saving from the livestock production system thus has been worked out to be 41.62 Mha.

The saving of soil nutrients due to use of dung as manure has been estimated to the tune of 0.541 Mt of nitrogen, 0.137 Mt of phosphorus and 0.541 Mt of potash. If these quantities of soil nutrients are to be replaced by the equivalent amount of chemical fertilizers, then 2.63 Mt of ammonium sulphate, 0.31 Mt of super phosphate and 0.82 Mt of murate of potash would be required. A tractor can replace about 10 working animals and at this rate, approximately 5.5 million tractors would be required to replace the existing stock of working animals, that will consume about 13 Mt of diesel annually. Burning of this much diesel would emit about 4.17 Mt of CO_2, which is equivalent to 0.199 Mt of methane emission.

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