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Adapting livestock water productivity to climate change

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Abstract

Purpose – The main purposes of this paper were to assess effects of smallholder farmers access to livelihood capital (e.g. land, livestock and water) on livestock water productivity (LWP) and to evaluate impacts of selected interventions in reducing livestock water demand (per unit of livestock product) and therefore increasing LWP.

Design/methodology/approach – A total of 203 sample farm households were selected in intensive and semi-intensive crop-livestock systems of Indo-Ganga basin of India. A household survey was undertaken to capture data on land, water and livestock management. For the analysis, sample farms were clustered into poor, medium, better-off. LWP is estimated as a ratio of livestock beneficial-outputs (e.g. milk) to depleted-water (i.e. evapotranspired water to produce livestock feed). Impacts of selected interventions, on LWP, were analyzed using scenarios developed on a spread sheet model.

Findings – The results showed different LWP values among farm-clusters and levels of intensification. The intensive systems showed higher LWP than the semi-intensive. In the baseline, dairy water demand to produce a liter of milk was higher than the world average: ranging between 1,000 and 29,000 L. Among the farm-clusters, variation of LWP was system specific and affected by farmers' access to virtual water trading (i.e. milk and feed). Improving milk productivity, feed quality and feed water productivity reduced livestock water demand per liter of milk substantially and, therefore, the saved water can be used to augment ecosystem services that can mitigate the impacts of climate change.

Originality/value – This paper revealed that in the study systems LWP, in the business as usual scenario, is low. But by improving animal productivity, quality feed supply and water conservation substantial volume of water can be saved.

Keywords India, Livestock, Water supply, Hydrology

Paper type Research paper

1. Introduction

Widespread water scarcity in different parts of the world is expected to be further aggravated by number of emerging threats. Those threats include climate change and attendant increasing demand for water. For example, rising global temperatures,

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as a result of climate change, will lead to an intensification of the hydrological cycle, resulting in dryer dry seasons and wetter rainy seasons. This also means that climate changing will have impacts on spatio-temporal distribution of water resources (Gosain *et al.*, 2006). For example, it was predicted that climate change will increase the mean annual rainfall, runoff and evapotranspiration (ET) in the Indo-Ganga basin (IGB), where this study was conducted. Since annual rainfall is concentrated during the monsoon season, it does not guarantee, however, availability of more water for agriculture during the eight remaining dry months of the year.

Unless available water resource is captured, saved and channeled to the needy ecosystems and time of the year, the impact will be a heightened risk of extreme and frequent floods and drought (Gosain *et al.*, 2006). Rodell *et al.* (2009) suggested that the agriculture sector has to produce more food with less water to mitigate the impacts.

In the IGB, mixed crop-livestock systems dominate (Erenstein *et al.*, 2007). Livestock contribute to the livelihood of farmers but at the same time, deplete large volume of water to produce their feed. Recent system scale study in the IGB (Haileslassie *et al.*, 2009c) indicated higher LWP values for intensive systems (i.e. higher fertilizer and water inputs areas, e.g. Hisar and Etawah Districts in Haryana and Uttar Pradesh States, respectively), than for semi-intensive systems (i.e. limited management inputs, e.g. Bankura District in West Bengal State). The authors suggested that the current livestock water productivity (LWP) value is low compared to the potential of mixed crop-livestock systems.

Peden *et al.* (2007) underlined the need to focus on a demand management-based adaptive strategy to unlock this potential. But, in these large-scale studies (Haileslassie *et al.*, 2009c), major gaps exist in terms of identifying areas of interventions for demand management and community groups, which are more vulnerable to climate change. Therefore, the purposes of this study were:

- (1) to examine the effects of smallholders' access to livelihood capital on LWP; and
- (2) to identify key areas of interventions and assess their impacts on water saving and LWP improvement.

2. Methodology

2.1 The study areas: location and characterization

Mixed farming systems which integrate both crops and livestock are typical in the study sites (IGB). In early 2009, reconnaissance field visits were made to Bankura, Hisar and Etawah Districts to identify focus villages and systems for this detail study. The following five systems representing different intensification gradients (intensive and semi-intensive, Thomas *et al.*, 1997) were selected.

(a) *Paddy-rice system (semi-intensive)*. The study villages are located in the Bankura District of the West Bengal State (Figure 1). In the paddy-rice system, rice (*Oryza sativa*) is the major crop. The main water input to the system is monsoon (Kharif) season rain. Production is mainly subsistent. Farmers manage different livestock species and breeds: cattle (*Bos indicus*), sheep (*Ovis aries*), and goat (*Capra hircus*). Grazing on common property resources (CPR) and rice residues are important feed sources. In the paddy-rice systems, climate change is already manifested through frequent dry spells and shortage of water to support crop production and other ecosystem services.

(b) *Irrigated wheat-cotton and wheat-rice systems (intensive)*. The study villages are located in Hisar District of the Haryana State and Etawah District of Uttar Pradesh State

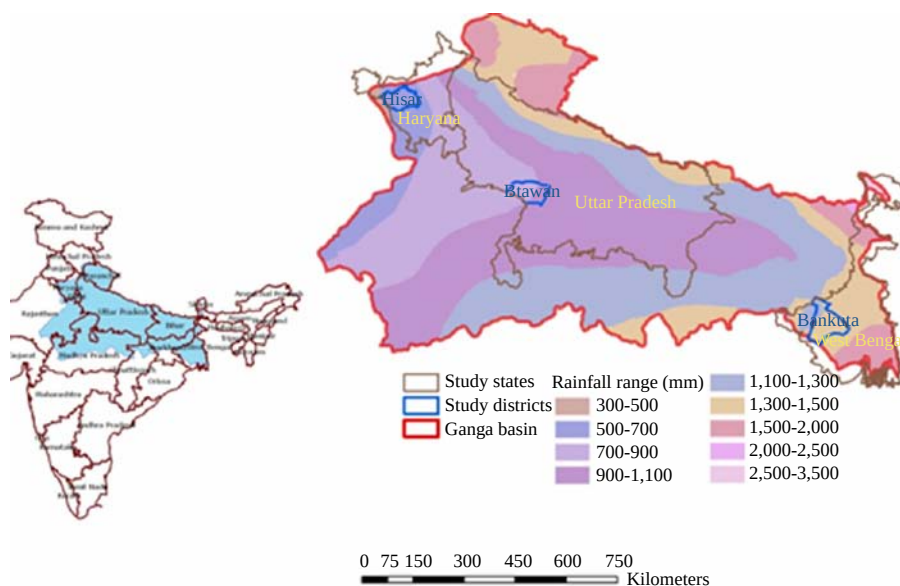


Figure 1.
Location of the study areas

of India (Figure 1). Wheat (*Triticum* species) is a major winter (Rabi) crop, while cotton (*Gossypium hirsutum*) has significant area coverage in summer (Kharif) season. In the wheat-rice variant, rice (*Oryza sativa*) dominates in summer (Kharif). Irrigation water (from canal and ground) is the major water source to supplement cotton and rice and to fully irrigate wheat. Compared to the paddy-rice system, these two systems are characterized by a higher crop diversity, intensity and productivity. The impact of climate change in these systems is less sensed by farmers as they are dependent on ground water. But Rodell *et al.* (2009) suggested that the current ground water extraction exceeds the natural recharge (in many parts) and thus these systems are also vulnerable to climate change. Areas under irrigated fodder, dairy structure and higher milk yielding breeds (compared with the paddy-rice system) generally reflect investment trends in the livestock sector. Shortage of irrigation water, increasing cost of livestock feed are some of the major challenges in the wheat-cotton and wheat-rice systems.

(c) *Millet-pulse and millet-mustard systems (intensive)*. The millet systems are pocket areas in Etawah and Hisar Districts (Figure 1). The millet system in Hisar District (Hisar Block II) was a wheat-based system at a time when canal water was available for irrigation but gradually shifted to traditional crops such as millet (*Pennisetum glaucum*) and chickpea (*Cicer arietinum*) mainly because of shortage of irrigation water in canals and poor ground water quality from the tube wells. The one in Etawah District (Chakarnagar Block) has no access to canal irrigation systems and thus mainly depends on Kharif season rain and the tube-wells. In both cases, farmers have a better access to feed and milk market (compared with paddy-rice) and investment in dairy is comparable with the wheat-cotton and wheat-rice systems.

2.2 Sample farm selection, survey and clustering

From the five systems, randomly, 203 sample (in proportion to the total household size in each systems) farm households were selected. A detail household survey

questionnaire covering: livestock holding, structure, productivity, land holding, feed production, feed and milk marketing and access to water were prepared, tested and used for the data collection. Before the analysis, sample farms were grouped into poor, medium and better-off clusters based on their access to typical livelihood capitals (i.e. agricultural land, livestock and irrigation water).

2.3 LWP estimation for the farm clusters

The concept and practices of LWP are elaborated in Peden *et al.* (2007), Hailelassie *et al.* (2009a) and Descheemaeker *et al.* (2009). According to these authors, evaluation of LWP can be carried out as a ratio of livestock outputs to water depleted (i.e. evapotranspired water, ET) for livestock feed production.

Milk is the livestock output considered in this LWP study. It was estimated as functions of the number of lactating cows in the farm cluster, their lactation period and daily milk production. This was converted to financial values based on 2009 farm-gate milk price. Estimation of feed water requirement of livestock needs linking metabolizable energy (ME in MJ) demand of the livestock and feed ME water productivity (MJ m^{-3}); (Hailelassie *et al.*, 2009c).

To establish feed ME water productivity, first, the water flows on the different land uses were determined using the soil water balance model called BUDGET (Raes *et al.*, 2006). Data sets (climate, soil and crop) to run the model were collected from field and literature (Allen *et al.*, 1998). BUDGET produced results on different water flows (e.g. ET, runoff). Normally, in a crop livestock system where residues are used for animal feed, ET must be partitioned between grain and agricultural byproducts (i.e. the feed). After estimating total ET harvest index and ME ratios were used to partition the water that must be factored into the livestock feed and grain (Hailelassie *et al.*, 2009c; Descheemaeker *et al.*, 2009). The partitioned water ($\text{m}^{-3} \text{ha}^{-1}$) was combined with different feed ME productivity (MJ ha^{-1}) to generate ME water productivity (MJ m^{-3}). The total feed ME demand of the livestock (for production, activity and maintenance) was calculated using King (1983) methods. To estimate the volume of water depleted by livestock, livestock's ME demand and ME water productivity were linked. Finally, values of LWP were estimated using the feed depleted water as a denominator and the livestock outputs (i.e. milk or its financial value, USD) as a numerator (Hailelassie *et al.*, 2009a,b,c).

2.4 Identification of interventions and assessing their impacts on LWP

Peden *et al.* (2007) suggested three basic strategies to increase LWP:

- (1) enhancing animal productivity;
- (2) improving quality and quantity of feed sourcing; and
- (3) conserving water.

The goals of these strategies and underlying interventions are generally increased milk yield, improved supply of sufficient and quality feed and improved water productivity of feed, respectively (Descheemaeker *et al.*, 2009).

After calculation of the LWP, key interventions pertinent to the above mentioned three strategies were identified. A participatory method was followed to comprehend potentials and limitations of these interventions from farmers' perspectives. For these interventions that were preferred by farmers, a productivity gap analysis was conducted to gain insights on the existing and achievable potentials. For the impact assessment,

values of these potential were built into the LWP spreadsheet model in a scenario fashion. These scenarios can be summarized as follows:

- (1) *Base scenario.* We used the current LWP value as a control.
- (2) *Achieving the potential milk yield.* In this scenario, we considered achieving potential milk yield of $15 \text{ L day}^{-1} \text{ cow}^{-1}$ in a mixed herd model and separated the levels into three: 9, 12, and 15 L of milk $\text{day}^{-1} \text{ cow}^{-1}$. Blümmel *et al.* (2009) suggested that this potential milk yield can be only achieved through increasing the dry matter intake (DMI) of cows from current 2.8 per cent body weight (BWt) to 4.8 per cent for low-medium quality feed. Thus, a DMI of 2.8 per cent for the control, 3.6 per cent for 9 L 4.2 per cent for 12 L and 4.6 per cent BWt for 15 L milk yield was applied.
- (3) *Improving feed quality.* In this scenario, it was assumed that improvement in milk yield should be accompanied by good feed quality ($\sim 8.5 \text{ MJ kg}^{-1}$). According to Blümmel *et al.* (2009) under good feed quality DMI will be less and thus suggested 3.1 per cent for 9 L, 3.6 per cent for 12 L and 4.2 per cent BWt DMI for the 15 L milk production $\text{day}^{-1} \text{ cow}^{-1}$. In this study, the same values of DMI at respective level of milk increase were applied. The obvious differences, between this and scenario ii, were the impacts of feed quality and reduced DMI on LWP.
- (4) *Achieving higher feed ME per a unit of depleted water.* This scenario takes the current crop and feed yield and respective water productivity gaps into account. In a mixed crop livestock system, where agricultural byproducts serve as animal feed, increasing crop water productivity is analogous to increasing feed ME water productivity. In IGB > 100 per cent yield gap between farmers practice and potential yield is reported. 20, 60 and 100 per cent increases in water productivity of feed ME, corresponding to the three levels of milk increase, were assumed and applied the same DMI as scenario (2).

3. Results and discussion

3.1 Water productivity of dairy cows: the base scenarios' implications for systems' resilience to climate change

Physical and financial LWP values, for dairy in different systems are depicted in Tables I-III. The milk water productivity in the wheat-rice, wheat-cotton and millet systems showed higher LWP values than the paddy-rice system (Tables I-III). This could be accounted for by difference in the milk productivity of cows and the feed ME water productivity. In wheat-rice systems, the volume of water used to produce a liter of milk showed lesser magnitude and narrower range (across breeds) when compared with Singh (2004). Contrastingly, the values for millet-pulse system were in good agreement with these previous studies. These variations can be explained by the difference in methodologies used to calculate LWP. For example, Singh (2004) used the lifetime milk productivity of cows and total irrigation water as an input. It should be also noted that Singh (2004) estimation was on the feed supply side.

A more compelling argument in this context is the intra- and inter-system variations of LWP. Although values in the wheat-cotton and millet-pulses were in good agreement with the system/district scale studies (Haileslassie *et al.*, 2009c), the values for the paddy-rice system showed a considerably higher volume of water depleted to produce a liter of milk (Table III). This is worrisome in times of growing concerns over water scarcity

Systems	Parameters	Poor farms			Medium farms			Better-off farms		
		Cross-breed	Indigenous	Buffalo	Cross-breed	Indigenous	Buffalo	Cross-breed	Indigenous	Buffalo
Wheat-cotton	Milk liter day ⁻¹	7.50	–	7.75	8.80	4.50	7.09	8.50	–	8.50
	Milk USD day ⁻¹	2.63	–	2.72	3.09	1.58	2.49	2.98	–	2.98
	ME demand MJ day ⁻¹	68.90	–	95.90	85.30	62.97	73.27	71.98	–	67.58
	ME water productivity MJ m ⁻³	5.63	–	5.63	5.88	5.88	5.88	6.15	6.15	6.15
	Water requirement m ⁻³ day ⁻¹	12.23	–	17.02	14.51	10.71	12.47	11.70	–	10.98
	Liter of water per liter of milk (0)	1.6	–	2.2	1.7	2.4	1.8	1.4	–	1.3
Millet-pulses	LWP_PHY	0.61	–	0.46	0.61	0.42	0.57	0.73	–	0.77
	LWP_FIN	0.22	–	0.16	0.21	0.15	0.20	0.26	–	0.27
	Milk liter day ⁻¹	–	–	7.50	5.00	6.00	7.50	12.00	7.00	6.70
	Milk USD day ⁻¹	–	–	2.63	1.76	2.11	2.63	4.21	2.46	2.35
	ME demand MJ day ⁻¹	–	–	82.22	70.82	70.43	102.81	100.96	74.70	83.97
	Feed ME water productivity MJ m ⁻³	–	–	4.52	4.65	4.65	4.65	3.70	3.70	3.70
	Water requirement m ⁻³ day ⁻¹	–	–	18.20	15.24	15.15	22.12	27.26	20.17	22.67
	Liter of water per liter of milk (0)	–	–	2.4	3.1	2.5	2.9	2.2	2.8	3.3
	LWP_PHY (liters of milk m ⁻³ of water)	–	–	0.41	0.33	0.40	0.34	0.44	0.35	0.30
	LWP_FIN (USD m ⁻³ of water)	–	–	0.14	0.12	0.14	0.12	0.15	0.12	0.10

Notes: LWP_PHY, physical livestock water productivity; LWP_FIN, financial livestock water productivity; ME water productivity is weighted by the percentage share of the different feed ingredient

Table I.
Livestock water productivity of dairy cows across farm clusters and farming systems (intensive systems, Hisar)

Table II.
Livestock water
productivity of dairy
cows across farm clusters
and farming systems
(intensive systems,
Etawah)

Systems	Parameters	Poor farms			Medium farms			Better-off farms		
		Cross- breed	Indigenous	Buffalo	Cross- breed	Indigenous	Buffalo	Cross- breed	Indigenous	Buffalo
Wheat-rice	Milk liter day ⁻¹	-	-	7.00	7.80	5.50	7.00	11.50	5.50	6.33
	Milk USD day ⁻¹	-	-	2.46	2.74	1.93	2.46	4.04	1.93	2.22
	ME demand MJ day ⁻¹	-	-	64.00	70.00	60.62	71.05	93.50	60.62	68.86
	ME water productivity MJ m ⁻³	-	-	5.26	8.71	8.71	8.71	5.99	5.99	5.99
	Water requirement m ⁻³ day ⁻¹	-	-	12.16	8.04	6.96	8.16	15.61	10.12	11.50
	Liter of water per liter of milk (0)	-	-	1.7	1.0	1.3	1.2	1.4	1.8	1.8
	LWP_PHY	-	-	0.58	0.97	0.79	0.86	0.74	0.54	0.55
Millet-mustard	LWP_FIN	-	-	0.20	0.34	0.28	0.30	0.26	0.19	0.19
	Milk liters day ⁻¹	6.00	-	8.00	-	5.00	7.07	9.00	6.00	6.80
	Milk USD day ⁻¹	2.11	-	2.81	-	1.76	2.48	3.16	2.11	2.39
	ME demand MJ day ⁻¹	55.78	-	55.53	-	66.94	74.06	85.30	50.27	53.60
	Feed ME water productivity MJ m ⁻³	6.21	-	6.21	-	5.28	5.28	6.86	6.86	6.86
	Water requirement m ⁻³ day ⁻¹	8.99	-	8.95	-	12.67	14.02	12.43	7.33	7.81
	Liters of water per liter of milk (0)	1.5	-	1.1	-	2.5	2.0	1.4	1.2	1.2
	LWP_PHY (liters of milk m ⁻³ of water)	0.67	-	0.89	-	0.39	0.50	0.72	0.82	0.87
	LWP_FIN (USD m ⁻³ of water)	0.23	-	0.31	-	0.14	0.18	0.25	0.29	0.31

Notes: LWP_PHY, physical livestock water productivity; LWP_FIN, financial livestock water productivity; ME water productivity is weighted by the percentage share of the different feed ingredient

Systems	Parameters	Poor farms			Medium farms			Better-off farms		
		Cross-breed	Indigenous	Buffalo	Cross-breed	Indigenous	Buffalo	Cross-breed	Indigenous	Buffalo
Paddy-rice	Milk liters day ⁻¹	—	1.0	—	—	1.2	—	3.5	1.9	—
	Milk USD day ⁻¹	—	0.36	—	—	0.43	—	1.27	0.69	—
	ME demand MJ day ⁻¹	—	45.30	—	—	45.48	—	61.00	45.42	—
	Feed ME water productivity MJ m ⁻³	—	1.54	—	—	1.75	—	2.33	2.33	—
	Water requirement m ⁻³ day ⁻¹	—	29.40	—	—	26.0	—	26.2	19.5	—
	Liters of water per liter of milk (0)	—	29	—	—	22	—	7	10	—
	LWP_PHY (liters of milk m ⁻³ of water)	—	0.03	—	—	0.056	—	0.13	0.10	—
	LWP_FIN (USD m ⁻³ of water)	—	0.01	—	—	0.02	—	0.05	0.04	—
Notes: LWP_PHY, physical livestock water productivity; LWP_FIN, financial livestock water productivity; ME water productivity is weighted by the percentage share of the different feed ingredient										

Table III.
Livestock water productivity of dairy cows across farm clusters and farming systems (semi-intensive systems, Bankura)

and rainfall uncertainty. Given that the present circumstance prevails, it will be a challenge for farmers in semi-intensive system to cope with the impacts of climate change. This is particularly true for farmers in the poor livelihood cluster and having indigenous cows (Table III). To explain this trend, we examined the feed sourcing strategies in the different systems and farm clusters. For example, the feed sources for livestock of the poor farm cluster (in semi-intensive, paddy-rice system) were primarily from CPR: communal grazing, fallow land and grazing in forest. As the result of over grazing and poor management these feed sources showed the lowest ME water productivity (MJ m^{-3} ; Table III) and thus impacted the volume of water depleted to produce a liter of milk.

LWP variation between farm clusters was system specific: in the paddy-rice system remarkable differences exists between the better-off and the poor, while in intensive systems these differences were not strong. The former substantiated the findings of (Hailelassie *et al.*, 2009b) who studied LWP for farm households with different access to resources in the rain fed farming systems in Ethiopia. In intensive systems (e.g. irrigated wheat-cotton and wheat-rice systems), farmers in all livelihood clusters had access to feed and livestock product marketing. Field data illustrated that farmers in intensive system sell 25-100 per cent of their milk products, while only 3 per cent farmers in semi-intensive system reported to sell 20 per cent. When we look at the market access of feed: in intensive systems 82 and 81 per cent of the sample farmers were trading for dry fodder and concentrate, respectively. In the semi-intensive system, only ~36 per cent sample farmers were involved in dry fodder exchange. Here, we argue access to market to be an incentive for the poor farmers to buy feed and invest on higher milk yielding breeds and thus maintain LWP comparable with the better-off farms. This argument was also revealed through insignificant differences of milk yields $\text{cow}^{-1} \text{day}^{-1}$ (at $p = 0.1$) among the sample farmers in different farm clusters in intensive systems (e.g. wheat-cotton, wheat-rice systems and the millet-pulse).

What is more appealing here that, in systems where feed is marketed, the fate of LWP values can be interdependent as the feed water productivity at feed sources (i.e. surplus feed producing better-off and medium farms) may influence the sink (i.e. the landless poor farms). These associations revealed the co-dependency of farm clusters in market oriented intensive system and thus suggest the need to improve system level resources flow and virtual water trading to increase LWP and systems' resilience to climate change. In conclusion, adapting water management to climate change is not only limited to direct investment in water saving techniques. Institutional services such as good access to inputs and outputs market encourages farmers to invest in water efficient technologies.

3.2 Interventions to improve LWP: adapting water management to climate change

In preceding sections, the baseline conditions of LWP were illustrated. Many key issues emerged from those exercises:

- What are the potentials and plausible interventions?
- What will be the impacts on LWP, if these potentials can be achieved?
- Which of these interventions can bring maximum gain in LWP?
- Which of the study systems and farm clusters must be prioritized for higher system resiliencies at the basin scale?

The following sections will explore into these questions.

3.2.1 Livestock management-based interventions. The livestock management based interventions focuses on practices (e.g. cross breeding, better veterinary services and quality drinking water supply for livestock) that can increase milk productivity. The current milk productivity of cows, intensive and semi-intensive systems was lower than the potential (Blümmel *et al.*, 2009). A stepwise improvement in cows' milk yield illustrated substantial advance in LWP value. Despite associated increase in the feed intake and, therefore, increased water depletion for the livestock feed production, in this scenario, the gain from milk was considerable and thus showed improved LWP values from the current >20,000 L of water per liter of milk to < 1,000 L of water per liter of milk in semi-intensive system (Figure 2b). Also for the intensive systems, a remarkable increase in LWP (Figure 2(a)) was observed.

Among the farm clusters those farms in the medium and poor clusters showed a greater gain (in water saving) compared with the better-off in all study systems. The difference in the volume of water saving, across intensification gradient can be accounted for by the difference in gaps of feed ME water productivity (i.e. between farmers practice and potential). In general, the findings of this study suggested that interventions that focused on the low productivity regions and poor farm clusters have higher potential for basin-wide livelihood improvement and water saving and thus it substantiates arguments of CA (2007).

3.2.2 Livestock feed-based interventions. The livestock feed-based intervention targets on practices that can help achieving medium quality feed (8.5 MJ kg^{-1}). Blümmel *et al.* (2009) argued that there are huge opportunities to improve the LWP by focusing on cultivars with higher ME values and dry matter (DM) digestibility. This is particularly true when crops like pulses (digestible and energy denser) constitute an important feed ingredient; physical (e.g. chopping) and chemical treatments (e.g. urea) of feeds are practiced. Sethi (1999) recommended a feeding schedule using locally available feed material in one of our study areas (Hisar District). When the DM of recommended ingredients was converted to ME values (weighted by their proportion in daily ration), it gave a feed density of $\sim 9 \text{ MJ kg}^{-1}$. This illustrates the prospect of achieving medium energy density level with locally available feed sources. The point is how much water can we save from such interventions?

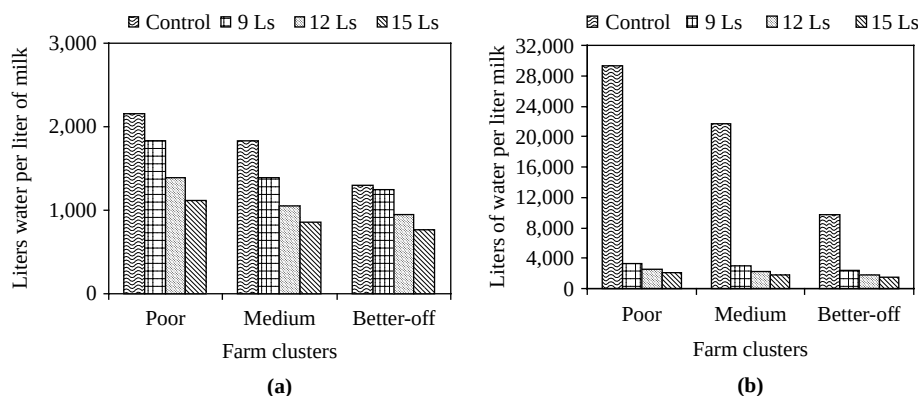


Figure 2. Impact of improving livestock management and achieving potential milk yield from a mixed herd model on dairy water productivity in intensive (a) and semi-intensive crop livestock systems (b) of Indo-Ganga basin

Note: Ls stands for liters of milk

Generally, improvement in feed quality impacts the volume of water required to produce a unit of animal products such as milk. The results of this study showed that as much as 120 m^3 of water $\text{year}^{-1} \text{ cow}^{-1}$ can be saved from this intervention (Figure 3(a) and (b)). Like for the livestock management-based scenario, more LWP improvement was observed for the semi-intensive system. The gain from this intervention was small compared with the livestock and water management based interventions (scenarios 2 and 4) and this should not be a surprise as the study targeted only medium quality feed. Had the target been higher quality feed (e.g. 12 MJ kg^{-1}) more water could have been saved. But such higher quality feed options are invariably stymied by smallholder farmers' inability to afford its price.

3.2.3 Water management-based interventions. These interventions include key agricultural activities that enhance sufficient and timely water supply and efficient uptake by the plants. Rice and wheat constitute the major food-feed crops in the study systems. Cai and Sharma (2009) showed an enormous gaps between farmers practices and potential yield (in IGB for those crops). For example, they indicated as high as 6.18 Mg ha^{-1} yields for rice in bright spot and as low as 1.18 Mg ha^{-1} in hot spot areas. According to those authors the average rice water productivity for IGB is 0.84 kg m^{-3} with minimum and maximum values ranging between 0.2 and 2.4. While for wheat, they showed a mean value of 1.36 with maximum and minimum ranging between 3 and 0.2 kg m^{-3} . Water productivity study for Hisar, Etawah and Bankura Districts (Hailelassie *et al.*, 2009c) indicated a wider range ($0.19\text{-}0.72 \text{ kg m}^{-3}$) for wheat.

In terms of feed water productivity, Singh (2004) reported a huge variation, for green fodder crops, in the State of Gujarat in India. For example, for alfalfa (*Medicago sativa*) they indicated water productivity values ranging between 2.3 to 9.1 kg m^{-3} and for maize (*Zea mays*) 2.12 to 6.39 kg m^{-3} . Hailelassie *et al.* (2009c) demonstrated enormous intra- and inter-system water productivity variation, for aggregated livestock feed ingredients in the study systems. A marked picture was particularly observed between the green fodder on irrigated and communal grazing land. The comparison of these figures with literature values (Singh, 2004) for commonly grown food crops (e.g. ground nut (*Arachis hypogaea*) which are water productive (14.04 kg m^{-3}) and superior in feed quality, demonstrates scopes for feed water productivity improvement.

Achieving potential yield implies increasing the feed ME water productivity by the similar magnitude. The result of impact assessments of these interventions

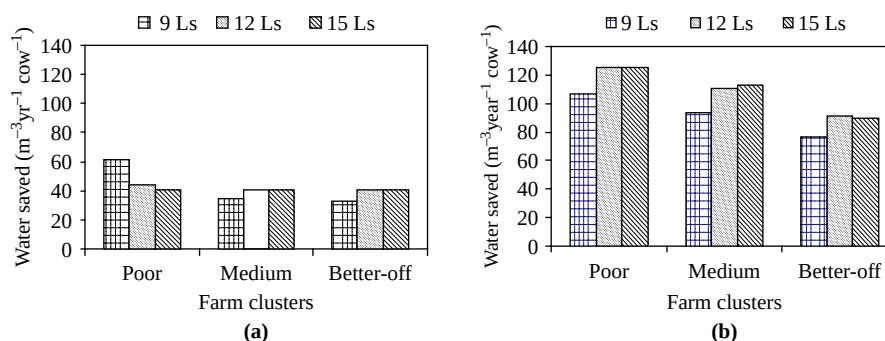


Figure 3. Volume of water saved by changing feed quality, from low to good in intensive (a) and semi-intensive systems (b) of Indo-Ganga basin

Note: Ls stands for liters of milk

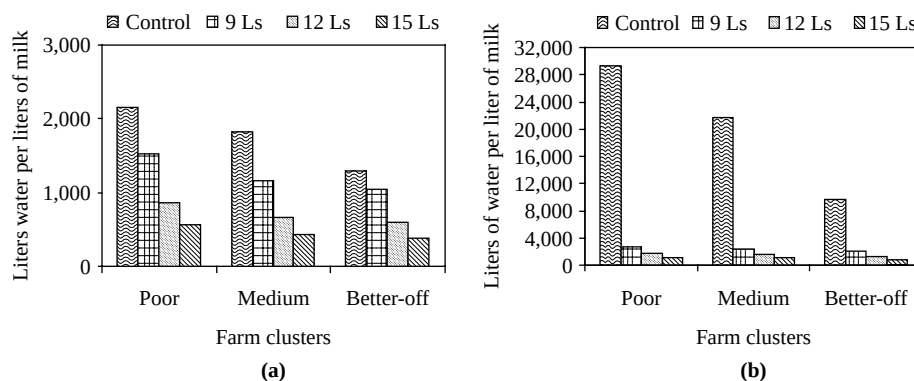
is shown in Figure 4(a) and (b). For the poor, those interventions showed strongest improvement in LWP compared with all other interventions. The point is, however, that the poor farmers have less access to land and their capability to improve the feed yield and, as a result, feed ME water productivity, is unrealistic under the current setting. A more relevant option is to improve access to feed market: feed that is produced through judicious water use. For the paddy rice systems (semi-intensive), improved management of CPR on which the poor depends will also help to improve LWP and mitigating the impacts of climate change.

The LWP model is more sensitive to change in feed water productivity compared with improved feed quality and animal productivity. This study's findings confirm previous studies (Descheemaeker *et al.*, 2009) which suggested that improvement of water productivity of feed changes LWP value significantly, compared to other interventions.

4. Conclusions

The overarching objectives of this study were to explore effects of smallholder access to resources on the magnitude of LWP and to assess interventions that can meet livelihood demands and at the same time, save water to mitigate impacts of climate change. In view of the results, the following conclusions can be drawn:

- The present livestock water depletion to produce a liter of milk is higher than the world average. However, intra- and inter-system variations in LWP indicate opportunities for its improvement and thereby increasing community resiliencies to climate change. By increasing the current milk yield level of a mixed herd model to its potential, it was possible to reduce water depleted to produce a liter of milk. There was also a considerable impact of feed water productivity intervention on LWP values and LWP model is more sensitive to change in water productivity of feed compared with other interventions. This demonstrates the relative role of better CPR management, selection of high yielding and better quality fodder crops to improve LWP.
- Apparently, by integrating the different scenarios water saving can be maximized. But for such attempts to be realistic a unique role, context and optimum combination of different interventions must be recognized and linked to input (e.g. feed) and output (e.g. milk) markets.



Note: Ls stands for liters of milk

Figure 4. Impact of improving feed ME water productivity on dairy water productivity in intensive (a) and semi-intensive crop livestock systems (b) of Indo-Ganga basin

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