



Contribution of integrated catchment and surface water management to livestock water productivity in pastoral production systems

Emmanuel Zziwa^{1*}, Swidiq Mugerwa², Brian Owoyesigire³, Denis Mpairwe¹

¹*Department of Agricultural Production, College of Agricultural and Environmental Sciences, Makerere University, Kampala P.O BOX 7062, Kampala, Uganda*

²*National Livestock Resources Research Institute, P. O. Box 96, Tororo, Uganda*

³*Buginyanya Zonal Agricultural Research and Development Institute, Mbale, Uganda*

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Abstract

Seasonal water fluctuations both in quality and quantity negatively affect livestock production and subsequently reduce livestock-water productivity (LWP) in rainfed pastoral production systems. This study aimed at assessing the effects of improved catchment and surface water management on LWP and to establish whether the effects of integrated catchment and surface water management are additive, synergistic or counteractive. Three pastoral production systems of Uganda (settled, semi-settled and non-settled) were considered under three management interventions (improved catchment management, improved surface water management and integrated catchment and surface water management) taking the base scenario as a control. Beneficial livestock outputs ($p = 0.155$), depleted water ($p = 0.76$) and LWP ($p = 0.488$) were not significantly different across production systems but were higher in settled and least in non-settled production systems. Improving catchment management increased LWP by 180%, 458% and 142% while improving surface water management increased LWP by 62%, 165% and 60% in settled, semi-settled and non-settled production systems. Integrated catchment and surface water management increased LWP by 353%, 518% and 280% in settled, semi-settled and non-settled production systems respectively. The effects of practicing integrated catchment and surface water management were hence synergistic and not additive. There exists a great potential for improving LWP in water stressed pastoral production systems of Uganda by reducing the amount of water depleted in production of animal products through practicing integrated catchment and surface water management interventions as well as increased utilization of crop residues in livestock feeding.

*Corresponding Author: Emmanuel Zziwa ✉ ziwaemma@yahoo.com

Introduction

Uganda's pastoral production systems are rainfed and water plays a very important role in determining the productivity of these systems. Understanding the efficiency with which rain water is harvested and utilized in production of animal feed, drinking and final transformation into livestock products and services is therefore critical for the development of strategic management practices for increasing water productivity. Livestock water productivity (LWP), often expressed in US dollars per cubic meter of water (USDm⁻³) is defined as the ratio of beneficial value of animal products and services to the amount of water depleted and degraded in producing them (Peden *et al.*, 2007).

Water is important for livestock production through drinking, feed production, maintenance of hygienic animal housing, and processing of meat, hides and skins. However, amounts of water used directly by livestock for drinking and other purposes are relatively small with much larger amounts being used to produce feed resources (Peden *et al.*, 2007). The efficiency with which water is stored and used for beneficial production determines how productive the system is. Therefore, catchment and water resource management practices that undermines water quality, availability and value to subsequent users decreases LWP (Molden *et al.*, 2003). In view of this, catchment management practices that improve water retention and transformation into pasture production will have significant impacts on LWP as more water is put to use.

Supply of inadequate and poor quality water to livestock adversely affects feed consumption and health consequently leading to reduced growth, reproduction and productivity of livestock (Beede, 2000; Patterson *et al.*, 2003). Presence of excessively high levels of some nutrients may have direct effects on the acceptability (palatability) of drinking water (Willms *et al.*, 2002) or may affect the animal's

digestive and physiological functions once consumed (Patience, 1994). The poor taste and odor in water is mostly imparted by fecal contamination (Willms *et al.*, 2002), excess minerals in water like nitrates and sulphates (Jordan and Tomaszewski, 2003), and decay of algae and plant material in water.

Poor catchment management practices such as overgrazing, opening of water ways and grazing in riparian areas reduce vegetation cover which increases the rate of soil erosion and runoff speed (Zhang and Schilling, 2006; Bhattarai and Dutta, 2007). This leads to the creation of gullies that carry runoff and manure into the reservoirs. The silt carried in runoff reduces reservoir capacity and manure introduces bacteria and nutrient elements which reduces water quality (Franeos, 2000; Alexandrov *et al.*, 2003). Poor surface water management practices such as direct access of animals to water resources for drinking and the presence of water cover plants affects water quality and quantity. Sugita *et al.* (2006) noted that cattle potentially affect water quality by (a) increasing the concentration of suspended solids due to the physical stirring up of the bottom sediments when they are in the water, and due to the increased runoff from grazed foreshores areas, (b) increasing nutrients in water either through direct deposit into the water or entrained in runoff entering the water body, thereby causing effects such as increased biological oxygen demand and (c) increasing fatal bacteria and potential pathogenic microorganisms, through direct defecation into the water, or in runoff from nearby areas. Therefore, poor livestock management practices can have a negative impact on water quality and thus affect production. Also, the presence of aquatic plants; *Lemna*, *Nymphaea*, *Pistia* and *Azolla sp* and algae have differing implications on the quality and quantity of water in surface reservoirs with some imparting an awful smell while others increasing water loss due to high evapotranspiration rates (Zziwa, 2009). Stringent measures are therefore required to regulate the density of water cover plants on reservoirs in order to maintain

acceptable water quality for livestock drinking. Therefore proper catchment and surface water management practices are a prerequisite for increasing livestock production and subsequently increase LWP.

Improved catchment and surface water management have major implications on LWP through increasing pasture production, water quality and availability which translates into more livestock products. However, it is not known whether sole management interventions or integrated management of catchment and water resources give more beneficial output LWP. Furthermore there is a need to establish whether the effects of integrated management are synergistic, additive or counteractive. This study was set to determine the contribution of improved upper catchment and water resource management on livestock water productivity in rainfed pastoral production systems of Uganda and to establish the effects of integrated catchment and water resource management practices on LWP.

Materials and methods

Study area

The study was undertaken in *Kiruhura and Nakasongola districts* which are found in the cattle corridor of Uganda. The livelihoods of communities, in the “cattle corridor”, are dependent on crop and livestock production, with livestock providing important livelihood to the communities in terms of providing meat, milk and cash (70% of livestock outputs are marketed compared to 33% for crops). The study was conducted in three pastoral production systems; the settled communities in Kiruhura district, semi-settled communities in Karungi sub county Nakasongola district and non-settled communities in Nabiswera sub county Nakasongola district. There are apparent differences in the degree of intensification of livestock management in the three production systems which stem from land ownership, water availability and livestock breeds.

Calculation of LWP

LWP was calculated using the spreadsheet model, developed by Hailelassie *et al.* (2006). This model was modified to a Metabolizable Energy (ME) concept to assess the relative impacts of synchronized land (upper catchment) and water based management interventions on the magnitude of LWP. LWP was first calculated based on the current status of land and water management practices that were practiced before implementing improved catchment and water management interventions. This was referred to as the ‘base scenario’. In this Intervention, consumption of available dry matter (Mugerwa *et al.*, 2008) by livestock was considered without accounting for the inefficiencies of dry matter uses due to inadequate drinking water supply for livestock. Dry matter yields of existing crop land (Owoyesigire *et al.*, 2008) and dry matter yield under proper land management (reseeding and manure application) (Mugerwa *et al.*, 2008) were factored into ME balance. Only the ME that is required by livestock to produce the different livestock products and services was considered and the land in excess of ME requirement was removed from the system (Hailelassie *et al.*, 2006). LWP was then estimated to see the impacts of catchment management on LWP under adequate supply of quality drinking water (Zziwa *et al.*, 2008). Finally a combination of land and water based management interventions were considered to see if integration would matter in improving LWP. Each production system was hence replicated four times.

Estimation of depleted water

The amount of water used in production of animal feeds greatly exceeds livestock drinking water requirements (Peden, 2007). Therefore, water lost in the process of producing animal feeds (Evapotranspiration) was used to estimate depleted water. The crop coefficient (Kc) and the evapotranspiration of the reference crop (EPo) approaches were used to estimate evapotranspiration. A pan evapotranspiration correction factor was used to

estimate EPo. Estimation of the Length of Growing Period (LGP) involved the use of New LocClim 1.06 (FAO, 2005). Finally, this was factored into EPo and (Kc) and areas under the different land use to calculate evapotranspiration values for the whole system in our study sites.

Quantification of Livestock products and services

This study focused on livestock products and services that could be methodologically quantified. Manure, milk, meat and traction were considered as the beneficial outputs and services. The household survey data (Owoyesigire *et al.*, 2008), was used to estimate milk yield which was converted to monetary values based on the current market price. Meat production was estimated using parameters such as off take rate, carcass weight and average slaughter age for different livestock species and applied similar procedures to estimate the values of hides and skins. Traction power is a very recently started livestock multiple use strategies in Nakasongola and was fixed on contractual basis of 1.5 USD ha⁻¹. The value of manure was estimated by converting the total number of livestock in the study area to Tropical Livestock Unit (TLU) using a conversion factor of 0.8 for cattle and 0.1 for sheep and goats (FAO, 2002). Dung production was calculated using dry weight daily dung productivity of 3.3 kg day⁻¹ TLU⁻¹ for cattle (Haileselassie *et al.*, 2006). In this study only Nitrogen (N), Phosphorus (P) and Potassium (K) and their concentration 1.4% for N, 0.2% for P and 1.8% for K as reported by (Mugerwa *et al.* 2008), were considered. This was finally converted to the fertilizer values using the 2008 market price of NPK.

ME was estimated using the crude protein (CP) and acid detergent fiber (ADF) of the feed in the study areas (Mugerwa *et al.*, 2008) using the formula:

$$ME (MJ/kg) = 14.3 + 0.017 CP - 0.019 ADF$$

Energy used for maintenance was estimated as the minimal requirements of energy to maintain the animal (Fasting Metabolism -FM):

$$FM (MJ/day) = 5.67 + 0.061 W \quad \text{Where: } W \text{ is live weight of animals in kg.}$$

The net energy requirements for gains (Eg) and the energy content of that gain are the products of the live weight of gain (LWG) and its energy value (EVg). For cattle the energy values of gain is related to the live weight in kg (W and energy stored in MJ (Eg) and was estimated as:

$$Eg = \frac{LWG(6.28 + 0.0188W)}{1 - 0.3LWG} MJ / day$$

Weight gain of 0.38 kg day⁻¹ was assumed.

To estimate the energy requirement for milk production, the current values of milk production (4 liters for local Ankole and 6 liters for crossbred cows) were used. This was converted to weight bases using 1.03 g/lit of milk density. The total milk produced was estimated using the survey results (6 months of lactation period for Ankole and 8 months of lactation period for cross breed cows) by Owoyesigire *et al.*, 2008:

$$MI (MJ) = 1.61 EVI$$

MI is energy for production of milk while EVI is energy value which was calculated assuming butterfat content of 36g/kg and solid-not-fat content of 86g/kg.

Maintenance Energy (FM) + Weight gain Energy (Eg) + Milk Energy (ML) = Total Energy requirements.

Finally, LWP was calculated using the formula;

$$LWP = \frac{\sum \text{Beneficial output (milk+meat+manure+traction)}}{\sum (\text{depleted water} + \text{degraded water})}$$

Data analysis

Data collected for beneficial outputs, depleted water and LWP from the three production systems were subjected to analysis of variance in XLSTAT 2012 and

Fishers' LS means were used to separate the means at 95% confidence interval.

Table 1. Livestock water productivity parameters for different production systems in pastoral communities of Uganda.

Management Intervention	Production system	Beneficial outputs (USD)	Depleted water (m ³)	LWP (USD/m ³)
Base scenario	Settled	465,968	6,248,580	0.075
	Semi settled	68,897	2,008,361	0.034
	Non settled	294,764	5,831,548	0.05
Improved upper catchment management	Settled	465,968	2,249,013	0.21
	Semi settled	460,792	2,431,012	0.19
	Non settled	294,763	2,431,012	0.121
Improved water resource management	Settled	763,787	6,248,580	0.122
	Semi settled	578,144	6,248,580	0.09
	Non settled	476,792	5,831,548	0.08
Integrated upper catchment and water resource management	Settled	763,787	2,249,013	0.34
	Semi settled	465,968	2,249,013	0.21
	Non settled	460,792	2,431,012	0.19

Results*Depleted water and livestock products and services*

The amount of water depleted for production of livestock products and services and the value of products and services under three production systems and three management interventions are presented in Table 1. Beneficial outputs ($p = 0.155$) and depleted water ($p = 0.763$) were not significant across the three production systems (Table 2) with the settled production system having high beneficial outputs (614,878 USD) and depleted water (4,248,797 m³) (Fig. 1). The semi-settled system had the least amount of depleted water (3,234,242 m³) and the Non-settled system had the lowest levels of beneficial output (381,778 USD) and LWP (0.11 USD/m³). There was a positive correlation ($r = 0.6$) between LWP and beneficial outputs whereas a negative correlation ($r = -0.6$) existed between LWP and depleted water. A weak

positive correlation ($r = 0.3$) existed between depleted water and beneficial outputs.

Table 2. LS means for beneficial outputs, depleted water and LWP.

Production system	LS means		
	Beneficial outputs (USD)	Depleted water (m ³)	LWP (USD/m ³)
Settled	614,878 ^a	4,248,797 _a	0.19 ^a
Semi-settled	393,450 ^a	3,234,242 _a	0.13 ^a
Non-settled	381,778 ^a	4,131,280 _a	0.11 ^a

Means followed by the same superscript are not significantly different at 95% confidence interval.

Improvement of upper catchment management did not increase beneficial outputs in settled and non settled communities but had an increase in semi settled communities while improving water resource management and integrated upper catchment and

water resource management increased beneficial outputs in all production systems. Settled and non settled communities depleted more water in the base scenario than semi settled communities. Least amounts of water were depleted under improved upper

catchment and integrated upper catchment and water resource management while high amounts of water were depleted under improved water resource management in all production systems.

Table 3. Percentage increase in LWP under three management interventions in comparison with the base Intervention.

Production system	Management Intervention		
	Improved upper catchment management	Improved water resource management	Integrated upper catchment and water resource management
Settled	180	62	353
Semi settled	458	165	518
Non settled	142	60	280

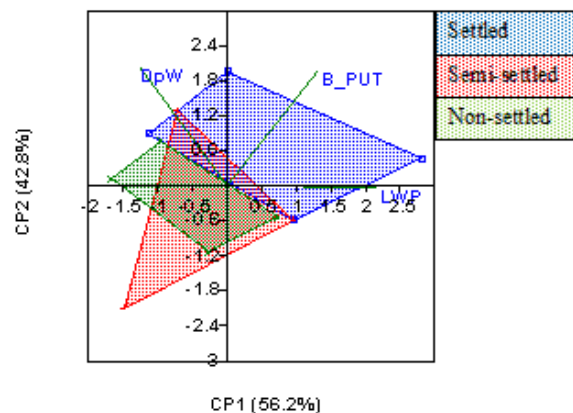


Fig. 1. A Principle Component Analysis scatter plot showing the variation of beneficial outputs (B_PUT), depleted water (DpW) and livestock water productivity (LWP) for the three production systems. CP (component). The correlation of B_PUT, DpW and LWP with components 1 and 2 were 0.6, 0.99, -0.58 and 0.79, -0.01, 0.8, respectively.

Livestock water productivity

Livestock water productivity was not significantly different ($p = 0.488$) across production systems, but the settled system had high levels (0.19 USD/m³) and least in Non-settled system (0.11 USD/m³) (Table 2). Improved upper catchment and water resource

management increased LWP in all production systems with higher increments being obtained in the settled and semi-settled systems as opposed to non-settled systems (Table 3). Improving upper catchment management increased LWP more than improving water resource management. However, integrated management of water and upper catchment greatly increased LWP in all production systems compared to sole management interventions of upper catchment and water resource management.

Discussion

The more water depleted in production of livestock products and services the lower the LWP value. This explains why a negative correlation existed between depleted water and LWP. The implication drawn here is that management and production systems that utilize minimum water to produce a unit of livestock products should be adopted for water stressed pastoral production systems. Water is depleted in a variety of ways that include evaporation, evapotranspiration, livestock drinking, degraded and many others. The existence of a weak correlation between depleted water and livestock products therefore signifies that the majority of water in the pastoral production systems is not put to beneficial use. The rangelands are

severely degraded with extensive bare lands and woody encroachment (Mugerwa *et al.*, 2011; Zziwa, 2011), as such, most of the rain water received is not used for pasture production and livestock consumption but is either lost as runoff downstream or used by trees (Zziwa *et al.*, 2008).

The non significance of beneficial outputs, depleted water and LWP among production systems may be explained basing on the non efficiency of all production systems in conservation and utilization of both blue and green water resources. Crop production is one of the major uses of water in agro-pastoral communities, however, there is limited utilization of crop residues as livestock feed in all communities and thus the low LWP (Owoyesigire *et al.*, 2008; Mugerwa *et al.*, 2012). In view of this, the LWP in systems such as the Ethiopian highlands where there is high utilization of crop residues as livestock feed is high (Peden *et al.*, 2007).

The higher beneficial outputs and LWP in the settled communities are attributed to the existence more water and pastures in these communities due to fencing of farms, clearing of bushes and weeds and construction of private valley tanks as opposed to the semi settled and non settled communities where no or little attention is put on pasture and water management. Also to note is the fact that settled communities have introduced high producing livestock breeds (Friesian for milk and Boran for beef). This increases livestock products (milk and beef) per unit livestock unit and thus a high LWP value.

The reason for higher increment in LWP under improved catchment management than under improved water resource management in all production systems is because more water is needed to produce livestock feed than is directly consumed by animals. As such, catchment management practices that aim at increasing forage availability resulted in more LWP than interventions geared to improving

water availability in reservoirs. This is in line with Peden *et al.* (2007) who noted that water needed for production of feeds may be up to 200 times higher than that used in livestock drinking. Also to note is the fact that restoring vegetation in the upper catchment has beneficial impacts on downstream water reservoirs through filtering of runoff (Zziwa, 2009). As such, integrated catchment and water resource management generates reduces the depletion of water through non-productive routes, increases forage and water availability and subsequently increases livestock production hence the higher LWP values. Alternatively, increased integration of crop residues in livestock feeding causes an increase in LWP as more productive water use routes (evapotranspiration) are exploited in livestock production.

Conclusions and recommendations

All management interventions had a positive effect on LWP in all production systems with integrated management approaches (integrating catchment and water resource management) giving higher beneficial outputs, lower amounts of depleted water hence higher levels of LWP. However, the increase in LWP as a result of integrated management is not additive of sole interventions but rather synergistic. There exists a great potential for increasing the livestock water productivity in water stressed rainfed pastoral production systems of Uganda through establishment and maintenance of vegetation in upper catchments, gullies and around surface reservoirs (improved catchment management), protection of valley tanks from direct animal watering, siltation and excessive evaporation (surface water management) and incorporation of crop residues in livestock feeding systems.

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