Tropentag 2015, Berlin, Germany
September 16-18, 2015

Conference on International Research on Food Security, Natural Resource Management and Rural Development
organised by the Humboldt-Universität zu Berlin and the Leibniz Centre for Agricultural Landscape Research (ZALF)

Agricultural Water Productivity Across Landscape Positions and Management Alternatives

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Introduction

Agriculture is expected to supply food for an ever increasing global population that is projected to reach 9.1 billion people by 2050 (UNPFA, 2011), out of which about 2 billion people will be living in Africa, which necessitate significant increase agriculture production to cope with the increasing demand, which can be achieved either through increasing the use of the necessary inputs or increasing productivity per unit of the inputs. Land and water are two of the most important agricultural production factors, but competition for these resources is growing including from non-food production sectors such as biofuel (FAO 2011). Globally, the option of bringing additional land under cultivation is becoming less feasible, due to limited availability of uncultivated land (Alexandratos and Bruinsma, 2012) and land degradation which taking land out of production.

In sub-Saharan Africa (SSA), access to land and water for agriculture remains a challenge for the smallholder farmers due to either unavailability or inaccessibility of uncultivated suitable land. According to Chamberlin et al. (2014), under the current conditions of infrastructure, production technologies and farm productivity levels, much of the SSA's potentially available cropland is either economically unviable or out of reach for the smallholder farmers. This entails that most of the additional food for current and future population must come from increased agricultural intensification (Headey and Jayne, 2014). Vast areas of currently cultivated land in SSA are producing at levels well below their potential showing a potential for increased production through agricultural intensification. Agricultural intensification (AI) can reduce expansion of crop land by allowing the local people satisfy their livelihood needs from the land already under cultivation (Byerlee et al., 2014).

Rainfed agriculture, which hosts the majority of the rural poor remains the predominant source of food production in the near future and maximizing its productivity will be paramount (Rockström et al., 2007; Turner 2004). In most part of the humid tropical SSA that receive good amount of rainfall the potential for increasing agricultural productivity is high (Erkossa et al., 2011). In the Ethiopian part of the Blue Nile Basin, agricultural productivity (with an average cereal yield of about 1 Mg ha^{-1}) is lower than that of SSA's average (Erkossa et al., 2009). Water availability and soil fertility are two of the key factors limiting productivity of the rainfed agriculture in Ethiopia. Therefore, identification, evaluation and proper use of practices that increase water availability and those that enhance its productive use are pre-requisite for ensuring sustainable intensification of agriculture in the area. Water productivity (WP) is defined as the ratio of the net benefits from crop, forestry, fishery, livestock and mixed agricultural systems to the amount of water required to produce those benefits; where water use refers either to water delivered to a use or depleted by a use (Molden and Theib, 2007). This ratio can be increased by either producing more with given water or producing the same amount with lesser water. The present study examined the hypothesis that landscape positions, crop types and varieties, and agronomic practices affect crop WP while the benefits in terms of crop-livestock systems' productivity can be augmented by improving livestock breeds and feeding practices.

Material and Methods

The study was conducted in two watersheds: Dapo (1,620 ha) and Meja (9,200 ha), located in the upper Blue Nile Basin in Ethiopia respectively (Figure 1). The watersheds have been divided into three landscape positions: **summit, mid-slope** and **foot-slope** based on the landscape characteristics (Figure 2). The crops that together cover at least 70% of each landscape position were monitored on 5 randomly selected farmer-managed plots (0.25 ha) in terms of crop variety and management practices. Crop performance indicators such as above ground biomass and grain for grain crops and tuber yield for potato were determined using five 1 m by 1 m quadrant samples from each plot. Both the biomass and grain were adjusted at 12 % moisture content after oven drying the samples, except for potato, which is usually sold fresh.

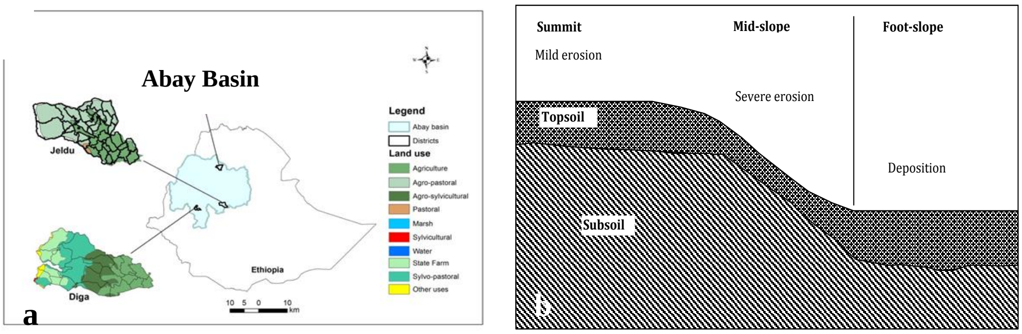

Figure 1: Location map of the study site (a) and a simplified view of the landscape positions (b)

Crop and livestock water productivity as a ratio between beneficial outputs (in physical and value terms) and water delivered to the system as effective rainfall (E*f*R) (Rockström and Barron, 2007) was estimated using Eq. 1-2. Effective rainfall (E*f*R) for the growing period was estimated using CROPWAT model (FAO, 1992), based on soil and climate data obtained from the nearest weather stations. The beneficial outputs were converted to their corresponding values using their respective local prices. The farm gate price for grain and tuber was obtained from local markets and the average price (ETB) per 100 kg was 520 for sorghum, 550 for finger millet, 900 for tef, 350 for maize and potato each and 500 for wheat and barley, where the average exchange rate in February 2012 (1 USD = 19.89 ETB) was used for conversion. Dry biomass of the crops was considered in assessing physical WP (eq. 1), while the aggregated crop yield and crop residue in value terms were considered in 'financial' crop-livestock system WP (eq. 2).

$$\mathrm{BCWP} = \frac{D\,(Gr + Re)}{EfR} \qquad eq.1$$

$$CLWP = \frac{Income\ (Gr + livestock)}{EfR} \qquad eq.2$$

Where:

BCWP = WP in terms of total dry biomass (kg m-3) with respect to E*f*R; D= percent dry weight; Gr = grain or tuber depending or crop type; Re = residues; E*f*R= effective rainfall (m^3), which is water available for use by crops during the growing season; CLWP = Crop-livestock System WP (USD m^{-3}) which is the sum of income from sell of grain or tuber and livestock products obtained due to feeding on crop residues

The yield and water productivity was statistically analyzed using the general linear model of SAS and the means were separated using the Least Significant Difference (LSD) at 95% confidence interval.

Results and Discussion

The biomass yield and the crop-livestock systems WP with respect to E*f*R were affected by natural and management factors. Landscape position, type and variety of crops grown, methods of planting, precursor crops and use of compost significantly affected the yield and crop water productivity. However, the two-way interaction between the factors was not significant, except for landscape position and compost use on biomass yield and water productivity, showing that each factor affects water productivity independent of the other. Irrespective of the landscape positions, the differences in yield and productivity between the two locations were significant that Jeldu showed consistently higher crop biomass yield and crop-livestock WP (Table 1). This may be related to the type of crops grown and the use of improved crop management practices. Potato, which is the most productive among the crops considered, is grown at Jeldu, but not at Diga. Besides, there is a greater use of improved crop varieties and management practices in Jeldu than Diga.

Table 1 Mean physical crop water productivity (kg m^{-3}) and crop-livestock water productivity (USD m^{-3}) by study site

Location	**Crop yield and water productivity**				**System water productivity (crop +livestock) (USD m^{-3})**		
	Biomass yield (kg ha^{-1})		Physical water productivity (kg m^{-3})		Current breed and feeding system	Improved breed and current feeding system	Improved breed and feeding system
	Grain/tuber	Residue	Grain/tuber	Residue			
Diga	1909^{B}	5703^{B}	0.44^{B}	1.28^{B}	0.23^{B}	1.11^{B}	1.24^{B}
Jeldu	10262^{A}	13515^{A}	1.73^{A}	1.59^{A}	0.51^{A}	1.65^{A}	1.81^{A}
LSD (5%)	689	1757	0.01	0.01	0.02	0.05	0.06

Values within the same column followed by the same letter are not statistically significant at 95% confidence interval; N= number of observations

Considering the landscape positions, the summit, followed by the foot-slope exhibited the highest crop-livestock system WP (Table 2). As it is generally dominated by gentle slopping plateau with relatively lower vulnerability to soil erosion, and the summit proximity to settlements to receive household wastes and manure including through night corralling of animals, it is the most fertile portion of the landscape. Its high fertility and less vulnerability of the crops to wild animals attack, the summit is preferred for high value crops such as potato. In their study conducted in areas adjacent to Jeldu, Haileslassie et al. (2006) reported a significant improvement in soil pH, available P, exchangeable K and Cation Exchange Capacity (CEC) in the upper part of the watershed (summit) as a result of manure application. In contrast, the productivity of the back-slope was the least, which is related to the prevailing sever degradation due to its steep slope and inappropriate land use and farming practices. Driven by poor crop productivity and high demand from construction sector for timber, farmers are changing the land use mainly in this part of the landscape from crop to eucalyptus (Desalegn and Erkossa 2013). Although they receive relatively low inputs similar to the back-slope, the foot-slopes are usually more fertile compared to the back-slope as they are the major sinks for alluvial sediments. They are generally reserved for grazing and cultivation of cereals. High biomass grains such as maize and sorghum are widely grown, which can be used as livestock feed. Therefore, their system WP increased from USD 0.27 m^{-3} under the current breed and feeding system to USD 1.66 m^{-3} when the livestock breed and management practice was improved as these enhance the utilization and conversion of the biomass, especially the crop residues into livestock products.

Table 2 Average yield, crop-livestock system water productivity for the three landscape positions and the livestock breed and feeding systems

Landscape position	Crop yield and physical water productivity				System water productivity (crop +livestock) (USD m^{-3})		
	Biomass yield (kg ha^{-1})		Physical water productivity (kg m^{-3})		Current breed and feeding system	Improved breed and current feeding system	Improved breed and feeding system
	Grain/tuber	Residue	Grain/tuber	Residue			
Summit	9463^{A}	4375^{C}	2.08^{A}	1.25^{C}	0.56^{A}	1.43^{A}	1.55^{AB}
Back-slope	2207^{B}	7341^{B}	0.42^{C}	1.27^{B}	0.21^{C}	1.10^{C}	1.20^{B}
Foot-slope	2957B	11277^{A}	0.47^{B}	1.72^{A}	0.27^{B}	1.49^{A}	1.66^{A}
LSD (5%)	1314	1859	1.98	1.98	0.06	0.28	0.32

Values within the same column followed by the same letter are not statistically significant at 95% confidence interval

Conclusions and outlook

Landscape positions, crop type, crop and livestock breed and management practices affect crop and crop-livestock system water productivity in the Upper Blue Nile Basin. While summit and foot-slope performed best in terms of physical crop water productivity and crop-livestock system water productivity, respectively, while the back-slope areas showed the poorest performance in all the productivity indicators. While integrating livestock into the system such that the crop residue is used as feed increased systems water productivity, but the increase was much higher in the foot-slope area where biomass productivity, including crop residues are the highest. The study made apparent the need for customizing crop and livestock breed and management practices with the potential of landscape positions. Integrating livestock into the system with their suitable management practices, especially in areas with high crop residue production potential enhances the overall benefit from farming systems. While reconciling the land use and management policies with scientific evidences such as this is suggested, the socio-economic issues such people's preference, market access and net economic benefit due to the alternatives needs to be established before issuing undisputable recommendations.

Acknowledgements- This study was financially supported by the Challenge Program on Water and Food (CPWF) and the CGIAR Humid Tropics program. The authors are grateful for their generous support. Our gratitude also goes to MSc students Addisu Asfaw and Negassa Bane for collecting the crop data. Yenenesh Abebe, IWMI GIS Officer helped in extracting the site-specific soil and climate data for the different locations within each watershed. We also acknowledge the contribution of Mequanint Tenaw who helped in parameterizing CROPWAT model. We appreciate also the helpful comments of two anonymous reviewers.

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