Agricultural Water Management 132 (2014) 120–128

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Enhancing farming system water productivity through alternative land use and water management in vertisol areas of Ethiopian Blue Nile Basin (Abay)

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ARTICLE INFO

Article history:
Received 10 May 2013
Accepted 11 October 2013
Available online 9 November 2013

Keywords:
Ethiopian Highlands
Waterlogging
Drainage
Crop-livestock system
Rainfed agriculture

ABSTRACT

Until recently, the Ethiopian government's investment did not systematically target high potential areas for agricultural intensification, limiting the potential productivity gains. Waterlogged vertisols, which cover about 2.7 million hectares in the Ethiopian part of the Blue Nile Basin, are among the high potential soils where management interventions could result in positive impacts. This study utilized soil, climate, crop and livestock productivity data and models to demonstrate intensification strategies which can increase crop-livestock system productivity. To understand the effects of alternative land use and water management interventions on water productivity, the areas have been classified into three drainage status depending on slope classes. Accordingly, non-drainable (0–2%), drainable (2–5%) and naturally drained (>5%) respectively, represented areas where artificial drainage is not feasible, where drainage using broad bed and furrows (BBF) is recommended, and areas where waterlogging is not a problem and no intervention is needed. Early planting of wheat (*Triticum* spp.) on BBF instead of the traditional late planting on flat beds in drainable areas and rice (*Oryza sativa*) cultivation instead of the traditional extensive grazing or growing grass-pea (*Lathyrus sativus*) on the flat areas provide viable alternative cropping options. Yield data of the crops and biomass of the native grass were obtained from research stations in the area while the effective rainfall and crop water requirement were estimated using CROPWAT Model. The value of the native grass and crop straw as livestock feed was estimated based on previous works. With respect to effective rainfall, the water productivity increase due to BBF over the control ranged from 5% to 200%, with an average increase of 57%. Despite higher water consumption of rice, feeding its residues to livestock enhanced the overall economic water productivity of the system as compared to the natural grazing or grass-pea cultivation. This can be accounted for by higher rice biomass productivity and the greater demand for its grain. The study demonstrated that draining the excess water when the slope allows, growing suitable high value crops on non-drainable areas, and integration of livestock into improved land and water management enhance overall agricultural system water productivity.

1. Introduction

The Ethiopian part of the Blue Nile Basin, locally known as *Abay*, covers about two thirds of the country's landmass and contributes nearly 40% of its agricultural products and 45% of its surface water. The mean annual rainfall ranges from 800 to 2200 mm in the north-eastern and southwestern parts respectively, making it favorable for rainfed agriculture. However, rainfed agricultural productivity remains low (Erkossa et al., 2009), mainly due to management rather than physical limitation (Benites et al., 1998). Traditionally, extensification was the major response to increased demand for food and feed. However, the availability of 'new' land suitable for cultivation is limited (Erkossa et al., 2011). The predominant low capital investment and limited technical capacity also imply that a wide-ranging transformation of traditional small scale rainfed agriculture to irrigated agriculture is unlikely to occur soon. Rainfed agriculture will remain the major source of livelihood in the foreseeable future. Therefore, increased food and feed production and rural livelihood enhancement must come from sustainable intensification of existing rainfed crop and livestock production system.

Intensification of the rainfed system requires the generation and adoption of integrated land, water, crop and livestock management alternatives. However, the extreme biophysical variations such as soil and climate of the basin pose daunting challenges to

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http://dx.doi.org/10.1016/j.agwat.2013.10.007

widespread adoption of technologies that were tested under specific conditions. The waterlogged vertisols that cover about 2.7 million hectares in the Abay Basin are among the high potential sites where intensification can significantly improve productivity as well as agricultural system resilience to shocks (Erkossa et al., 2009). One major impediment to intensification in the area is the hydrological properties of the soils, manifested by their slow internal drainage, with infiltration rates between 2.5 and 6.0 cm day^{-1} (Erkossa et al., 2004). According to Debele (1985), the Ethiopian vertisols occur on landscapes with a general slope ranging from 0 to 8%, but the majority have a 0–2% slope range, which restricts surface drainage and leads to seasonal inundation.

The traditional response to these drainage related problems includes planting of local cultivars with low productivity at the end of the rainy season after the major part of the water has evaporated, or leaving the land for native pasture to establish. This is common in the low lying areas which represent valuable grazing during the dry season. Empirical evidence suggests that the traditional management significantly reduces the length of the effective growing period, maximizes evaporation loss, exposes crops to terminal moisture stress and thus reduces water productivity of crops (Erkossa et al., 2011).

Studies conducted in various agro-ecologies in Ethiopia and India have shown that surface drainage of vertisols allows early sowing, enabling the utilization of the potentially available growing period (El-Swaify et al., 1985; Astatke and Kelemu, 1993) while suppressing evaporative losses (Erkossa et al., 2011). Broad bed and furrows (BBF) made by the Broad Bed Maker (BBM) developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), India (El-Swaify et al., 1985), have been modified to fit the smallholder systems in the Ethiopian Highlands and are now widely adopted (Astatke et al., 1995; Erkossa et al., 2011; Haque et al., 1996; Muhamed-Saleem and Astatke, 1996). However, application of the BBF is limited to areas having slope of 2–5% as it requires a slope steep enough for drainage while avoiding erosion. Most vertisol areas in the Abay Basin occur on slopes of less than 2% necessitating the use of other options such as high yielding waterlogging tolerant crops. Depending on the growing season temperature, rice (*Oryza sativa*), tef (*Eragrostis tef*) and forage crops can be grown in these areas. Several authors argue that rice is one of the best and cheapest ways of using the flooded and waterlogged soils by small-scale farmers in Ethiopia (e.g. Seyoum et al., 2011; Tadesse et al., 2013). Currently, rice cultivation is expanding into the Fogera, Metema, and Pawe plains, areas which are known for their extensive vertisols coverage (Gebrekidan and Seyoum, 2006). The replacement of extensive grazing with crops such as rice may provide grain for food and crop residues for animal feed, thereby increasing system water productivity.

Crop water productivity (CWP) is a measure of beneficial output of a crop or cropping system in relation to the water actually consumed (ETa) (Eq. (1)) or delivered (effective rainfall for rainfed system (eff)) (Eq. (2)) (Rockström and Barron, 2007):

$$CWP_{ETa} = \frac{Y(\text{kg}, \$)}{\text{ETa}} \tag{1}$$

in which CWP stands for crop water productivity, Y for grain yield in kg or its value (USD) and ETa for water actually consumed by the crops, and

$$CWP_{eff} = \frac{Y(\text{kg}, \$)}{\text{eff}} \tag{2}$$

in which CWP and Y are same as in Eq. (1) and eff stands for effective rainfall during the growing period.

Water productivity can be used as an indicator for sustainable agricultural intensification, especially in areas where water is scarce. It can be expressed in physical or economic terms. The objective of this study was to assess the impacts of alternative land, water and crop management practices on water productivity of the mixed crop-livestock system in the vertsol areas of the Blue Nile Basin.

2. Materials and methods

2.1. The study areas: location and biophysical settings

This study was conducted on the vertisol areas in the Ethiopian part of the Blue Nile Basin (Fig. 1). The Basin is characterized by highly rugged topography with altitudes ranging from 490 m to over 4250 masl (meters above sea level). Rainfall in the Basin generally increases with altitude but due to interference caused by local or extensive 'rain-shadow' effects, windward slopes receive higher rainfall than the leeward slopes. Although the main rainy season from June to September–October contributes 50–90% of the annual rainfall, its onset and secession is often uncertain.

Due to the variation in landscape and other soil forming factors like climate and vegetation, the soils of the Basin are highly variable and are severely degraded because of the prevailing poor management (Haileslassie et al., 2005). Four soil types, nitisols, leptosols, luvisols and vertisols, cover over 80% of the Basin (Erkossa et al., 2009). The vertisols are considered to have high potential due to their good inherent fertility and their location on flat to gentle slopes. About 90% of the vertisols in the Basin are located on a nearly flat (0–2%) slopes.

2.2. The farming systems

The farming systems of the Basin can be broadly categorized into the mixed farming of the highlands and the pastoralism/agro-pastoralism of the lowlands (Erkossa et al., 2009). Over 90% of the cultivated area is covered by the cereal based farming system, which encompasses *single cropping*, *double cropping* and *shifting cultivation* sub-systems (Erkossa et al., 2009). The productivity of the major crops grown on vertisols in the mid to highlands, such as wheat, is hampered mainly by waterlogging. Traditionally, wheat is planted in late August on flat beds toward the end of the growing season to avoid the waterlogging problem. The use of broad bed and furrows (BBF) to drain the excess water during the early growing season allows early sowing and enables the utilization of the available growing period (Erkossa et al., 2011). However, suitability of BBF is limited mainly by slope gradient, as major parts of the soils are situated on nearly flat areas where drainage is impossible without significant earth moving. Traditionally, the flat vertisol areas in the Basin are left for grazing as they are extremely waterlogged and cropping is often practiced late in the season after the standing surface water has evaporated. Grass-pea is favored, mainly because of its tolerance to the inevitable moisture stress induced by the late planting practice and its high biomass yield. Recently, both upland and flooded rice were introduced and expanding in the low and mid altitude areas as the daily minimum temperature is limiting in the highlands (Gebrekidan and Seyoum, 2006).

2.3. Analytical framework, tools and data source

2.3.1. Analytical framework and the alternative land use

Depending on the slope gradient, the landscape position on which vertisols are located was divided into (Fig. 2):

i. non-drainable (0–2% slope);
ii. drainable (2–5% slope);
iii. steep enough to drain passively (>5%), for which no assessment was made in this paper.