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Enhancing farming system water productivity through alternative land use and improved water management of rainfed agriculture in Vertisol areas

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Abstract: Waterlogged Vertisols are amongst the high potential soils where management interventions could result in positive impacts. This study utilized soil, climate and crop and livestock productivity data and models to demonstrate intensification strategies which increase crop–livestock system productivity and to understand the effects of alternative land use and water management options on water productivity in the Vertisols areas. The areas have been classified into three slope classes including areas where artificial drainage is not feasible, where Broad Bed and Furrows (BBF) can be used to drain the excess water and naturally drained areas, represented by areas with 0–2%, 2–5% and over 5% slope steepness, respectively. Early planting of wheat (*Triticum* spp) using BBF on drainable areas and rice (*Oryza sativa*) or grasspea (*Lathyrus sativus*) on the flat areas were compared with the traditional practices. Yield and biomass data were obtained from research stations in the area whilst the effective rainfall and crop water requirement were estimated using CROPWAT Model. The feed value of the native grass and crop straw 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 the rice, feeding its residues to livestock enhanced the overall economic water productivity of the system over the natural grazing or grasspea cultivation. Consequently, use of BBF enables growing high value or food crops of choice that may be sensitive to waterlogging whilst tolerant crops can be grown on flat lands allowing utilization of the full growing period. Coupled with livestock integration into the system, the alternatives can enhance food production and resource use efficiency from these 'marginal' areas.

Key words: Ethiopian highlands, waterlogging, drainage, crop–livestock system, Blue Nile

Media grab: This study has demonstrated that significant agricultural water productivity enhancement can be achieved in both crop and livestock components as well as overall farming system in environmentally constrained areas such as the water logged Vertisols in the Nile Basin.

Introduction

Intensification of rainfed agriculture requires generation and adoption of integrated land, water, crop and livestock management alternatives. However, extreme biophysical variations in the Nile Basin pose daunting challenges to widespread adoption of technologies that were tested under specific conditions. The waterlogged Vertisols that cover about 2.7 million hectares in the basin are among the sites where intensification can significantly improve agricultural productivity as well as 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). The traditional response to the impeded drainage includes planting of local cultivars at the end of the rainy season or leaving it for native pasture. Empirical evidence suggests that traditional management significantly reduces the length of the effective growing period, maximizes evaporation, exposes crops to terminal moisture stress and reduces water productivity (Erkossa et al. 2011). Studies conducted in various agro-ecologies in Ethiopia and elsewhere have shown that surface drainage using Broad bed and furrows (BBF) allows early sowing, enabling the utilization of the full growing period (Astatke and Kelemu 1993) while suppressing evaporative losses (Erkossa et al. 2011). However, the use of BBF is limited to areas having slope of 2–5% as it requires a slope steep enough for drainage. Depending on the growing season temperature, rice (*Oryza sativa*), teff (*Eragrostis tef*) and forage crops can be grown in areas where surface drainage is not an option. The overarching objective of this study was to assess the impacts of alternative land, water and crop management practices on water productivity (WP) of the crop–livestock system and its components.

Materials and methods

Depending on the slope gradient (%), the Vertisol areas have been divided into (Figure 2): i. Non-drainable (0–2%); ii. Drainable (2–5%); iii. Steep enough to drain passively (>5%). The alternative interventions evaluated include early sowing of wheat using BBF for the drainable areas and rice cultivation for the non-drainable areas, provided that the daily minimum temperature during the growing season remains above 10°C. The traditional uses, i.e. late sowing of wheat on flat beds for the former and growing grasspea (*Lathyrus sativus*) or natural pasture for the latter were treated as controls. The common wheat and rice varieties, HAR2029 and X-JIGNA, were used. The Crop Water Requirements under the alternative practices were estimated using the CROPWAT 8.0 model (Richard et al. 1998). The grain yield of wheat was obtained from published literature while the straw yield was estimated using an average harvest index of 0.41 (Birhanu 2010). Similarly, the grain yield of rice was obtained from demonstration fields where the straw yield was estimated using a harvest index of 0.44 (Seyoum 2006). Crop water productivity was estimated as a ratio of the crop yield or its equivalent gross economic value estimated based on farm gate price to the actual evapotranspiration or the potentially available water (effective rainfall). To estimate the livestock water productivity, the feed biomass (crop straws) productivity from the traditional and alternative land and water management were converted to ME in MJ kg^{-1} using literature values on energy content. The number of TLU that the energy per hectare can support under the traditional practices, the alternatives was estimated and linked to the benefit per TLU to calculate total livestock outputs and services per ha. To estimate system water productivity both crop and livestock outputs were converted financial values and the sum was divided by the potentially available or consumed water to produce them.

Results and discussion

Water productivity on drainable areas

Early sowing of wheat on BBF increased average biomass yield by over 63% as compared to the traditional late sowing on flat seedbeds. The increased grain yield may enhance the food security and livelihoods of the households both through improved food availability and increased income through sale of the products. The benefits of additional straw or crop residue production depend on how it is used, which can include: direct incorporation into the soil; feed to the livestock and return the manure to the soil; use as soil mulch, building material or as fuel. It may also be sold. Depending on the decision of the household on the type of use, the increased biomass production may enhance agro-ecological sustainability through increased soil organic matter or improve household livelihoods as a direct benefit. The effective rainfall during the growing period ranged from the highest of 7990 m^3 ha^{-1} at Pawe to the lowest of 4770 m^3 ha^{-1} at Enewari. Similarly, Pawe exhibited the longest length of growing period (LGP) of 191 days, as opposed to Dogollo that had the shortest (114 days). On the other hand, the highest (3,168 m^3 ha^{-1}) and the lowest (2804 m^3 ha^{-1}) actual crop water consumption (ETa) were at Bahir Dar and Merawi, respectively. Evidently, advancing the sowing date of wheat using BBF increased consumptive use of water over the traditional late planting on flat beds irrespective of the locations, but the magnitude of the increase varied with location, ranging from the lowest (15%) at Merawi to the highest (177%) at Enewari. This may be related to the extended growing period (184 days) at the latter site, which led to less effective consumption of water by the crop.

Early sowing of wheat on BBF increased the crop water productivity (CWP) with respect to effective rainfall, as compared to late sowing on flat beds, but it was reduced with respect to ETa, indicating that higher water productivity with respect to consumed water does not necessarily mean higher crop yield. While the average increase in CWP due to BBF was about 57%, it ranged between 5% at Enewari in 1986 and 200% at Merawi in 2007. Therefore, advancing the sowing date of wheat on Vertisols using BBF increased the productive use of the potentially available water, most of which otherwise would have been lost to evaporation (Erkossa et al. 2011). The spatial and temporal variation in the effect suggests the need for targeting interventions to optimize the return to available water. On average, the use of BBF increased the gross return (GR) from wheat grain by 50% as compared to that of flat beds with the highest GR of 1282 USD ha^{-1} at Bahir Dar in 2007 under BBF as opposed to the lowest of 296 USD ha^{-1} at Merawi during the same year under the traditional method. The use of BBF increased the Gross Economic WP with respect to effective rainfall by up to 183% at Merawi in 2007 despite its increased water consumption. Overall, every cubic meter of water resulted in an average gross return of 0.14 USD from the wheat sown early on BBF, a 36% increase on the previous 0.09 USD gross return obtained when the crop was sown late on flat beds. Similar to the case with crops, the use of BBF significantly improved the value of livestock products and services. The highest value was estimated for Merawi, which is in line with the effect on biomass production.

Water productivity on non-drainable areas

Changing land use from native grass to rice or grasspea on flat Vertisols increased crop water consumption by 152 and 10%, respectively. This is attributed to the fact that rice consumes more water per day for a longer duration (148 days) as compared to grasspea that was sown late and required only 90 days to mature. Consequently, the biomass water productivity with respect to effective rainfall was 0.4, 1.0 and 1.8 kg m^{-3} for native grass, rice and grasspea, respectively. Despite its high biomass production and water productivity, grasspea can be risky both as food and feed due to its high content of anti-nutritional agents, especially β-ODAP neurotoxin, which can lead to a disease known as lathyrism (Sharma et al. 2003) if consumed beyond a limited quantity. The beneficial outputs and services from livestock was the lowest where non-drainable Verstisols are used for rice but this can be improved by supplementing the practice with a second crop like grasspea.

System water productivity

As shown in Figure 1, all proposed alternatives showed higher system water productivity compared to the traditional practices at system level. Despite having the highest water consumption, the highest gross return and system water productivity was recorded under the rice–livestock system, closely followed by the grasspea–livestock system. This can be explained mainly by the high value of rice on the Ethiopian market and the fact that the straw can be fed to the livestock. A number of studies argue that sustainable water use through improved water productivity focuses on producing more agricultural products using the same or lower quantity of water input (e.g. Haileslassie et al. 2011). The decision on whether to go for high value but water depleting crops or a lower value crop which depletes less water is one with economic and political dimensions. However, in this particular situation, the opportunity cost of the extra water consumed by rice is insignificant as it is largely lost to evaporation under the traditional system. The BBF-wheat system also increased both the gross return and water productivity at system scale, confirming the previous findings in which it was recommended as a profitable alternative (Erkossa et al. 2006), even when water consumption is considered.

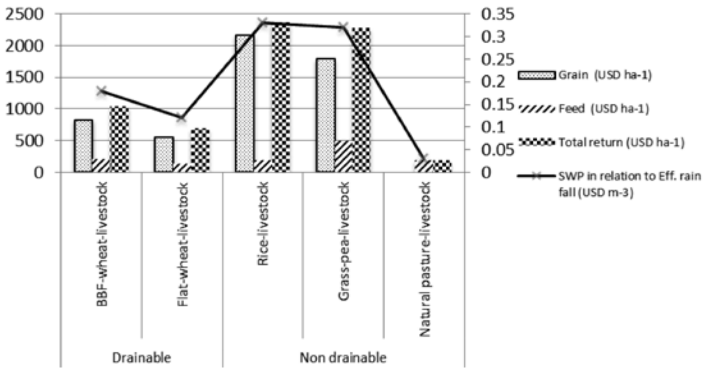

Figure 1. Effect of the alternatives on system water productivity in relation to effective rainfall

Conclusion

Based on primary data generated by the authors, secondary data obtained from published and grey-literature sources and model outputs, this study has demonstrated that significant agricultural water productivity enhancement can be achieved in both the crop and livestock components as well as overall system scales in environmentally constrained areas such as the highlands of Ethiopia. Improving crop productivity on soils which are hydro-physically constrained such as Vertisols, either using surface drainage technologies where the slope gradient is suitable, or growing hydrophilic crops such as rice in areas where drainage is limited by topography have been proven to be superior both in terms of gross return and efficiency of water use. The profitability is even higher when livestock is integrated into the system through using the dry matter as feed, the productivity of which was increased due to the use of the improved land and water management options.

Evidently such interventions enhance the livelihood of subsistence farmers and boost resilience of their environment. With increased market access for the products such as rice and livestock outputs, the widespread use of the alternatives within the basin and beyond can meaningfully contribute to the efforts to ensure national food security and spurs the overall economic growth. In view of ensuring high system productivity of the 12 million hectare Vertisols in the country, these integrated approaches need to be disseminated using a well guided strategy with the involvement of relevant stakeholders. In addition, provision of enabling policy and institutional environment that stimulate the wider adoption of improved management practices need to be in place. In the meantime, further refining of the alternative soil, water, crop and livestock-related technologies through research for development need to be invigorated.

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