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Conjoining rainfall and irrigation seasonality to enhance productivity of water in rice irrigated farms in the Upper Ruaha River Basin, Tanzania

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Abstract

Improving productivity of water in agriculture (*more crop per drop*) has been identified as an urgent global priority. However, there is lack of knowledge to inform the necessary strategies and actions for achieving this goal. A study was conducted to assess water utilization and productivity in one of large rice irrigation schemes in the Upper Ruaha River Basin in Tanzania. The water balance approach was applied to determine the components of water use and crop productivity. Rainfall analysis was done for trends and variability in relation to the on-set, cessation and their likely contribution during the rice-growing season using data of ten years from the meteorological station in the study area. The gross water use for growing rice was 2300 mm/ha, of which 28% was used for wetting up the fields during land preparation. With an average effective rainfall of 500 mm, irrigation requirement was estimated to be 1800 mm and productivity of irrigation water was less than 0.3 kg/m^3. The findings from this study show that productivity of water can be improved relatively easily up to 9% from the current levels if the transplanting season coincides with rainfall between the last decades of December and January, the period with sufficient and uniformly distributed rainfall. This conjunctive use of water leads to shorter season lengths and savings of water that can then be considered for allocation to other intra or intersectoral uses.

Keywords: Productivity of water; Water balance; Water use; Irrigation requirement; Water saving; Rice irrigated farms

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1. Introduction

Improving productivity of water in agriculture has been identified as an urgent global priority. One major reason, which highlights the importance of the concept of productivity of water, is the increase in demand for water resources in the last 15 years as a result of increasing population and the recognition for environmental water needs. It is argued that more water should therefore be directed to uses with a higher economic return per unit water, such as industries and high value crops that may use less water (Guerra et al., 1998). Increase in diversion from irrigation systems for non-agricultural uses will therefore reduce supply of water for food crops such as rice, which requires not less than 5000 l of water for every 1 kg of rice produced (IRRI, 2003). However, cereal production and rice in particular plays an important role for livelihood sustenance in developing countries inspite of large amount of water consumed. The

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Upper Ruaha River Basin for example contributes about 14% of the total annual rice production in Tanzania, which is equivalent to US$531 per annum per household practicing irrigated paddy (Kadigi et al., 2003). Thus, the challenge is to improve productivity while maintaining local livelihoods dependent on agriculture in places where few alternatives for water use or livelihoods exist.

Several techniques can be applied to improve productivity of water in agriculture depending on the environment, soil and other conditions under consideration. Under basin perspectives, three major paths based on supply and demand responses have been advocated for increasing agricultural production from water resources. These include developing more supplies through diversion and storage; secondly, a more depletion of developed primary water for beneficial uses; and thirdly producing more output per unit depletion (increasing productivity of water) (Molden et al., 2001). The first option relates to physical and economic availability of water resources and is not much on the agenda of developing countries whose economies are incapable of supporting new infrastructure development. The second and third options offer an opportunity for balancing water for food and environmental security, which has to a great extent been realized in large parts of the Asian countries (Dong et al., 2001). While considering a river basin as a unit for management of water resources, there are a series of best bet options that can be applied at catchment, system and field levels. Such options include among others minimizing variability of water supply through conjunctive use of alternative water resources, application of water saving practices, enhancing rainfall use in irrigation systems, and the use of good agronomic practices (Seckler, 1996). Options applicable at field level may not hold on the other hand when analysing water resources management at system or basin levels. The scaling up of field level strategies for example into scheme, system and basin levels is one of the stumbling block for strategies of improving productivity of water in irrigated agriculture (Guerra et al., 1998; Molden, 1997) partly because of the embedded nature of multifaceted factors and the failure to integrate the concepts of water reuse processes while considering true saving of water from irrigation systems (Seckler, 1996).

The improvement of productivity of water at farm level is an inevitable strategy apart from considering that it may end into a zero sum game theory [1] for integrated water resource management in a river basin (Molden and de Fraiture, 2003). The improvement of productivity has a direct benefit for improving livelihoods of farmers in sub-Saharan Africa because of increased productivity at unit level. In addition water management under surface irrigation systems in most sub-Saharan Africa is rarely in a position to be congruent with the theory of zero sum game due to factors such as the nature of soils, minimum mechanized irrigation operations and opportunistically non-binding water right institutions for managing water resources for irrigation.

Conventionally, the greatest improvements of productivity of water in irrigation have not been from better irrigation technology or management but rather from increased crop yields due to better seeds and fertilizers (Molden and de Fraiture, 2003). However, the use of rainfall water may play an important role in improving productivity of water through reduction of surface water deliveries. Most crop failures in sub-Saharan Africa are mostly due to deficit in soil moisture (Hatibu and Mahoo, 2000) caused by dry spells. And yet rainfall accounts for about 60% of the world staple food production and probably 90% for sub-Saharan Africa under direct rainfed agriculture (Savenije, 2001; Hatibu, 2002). The improvement of some types of irrigation infrastructure for example in Tanzania (including the Usangu plains) disproves the notion that modernisation necessarily improves irrigation efficiency and irrigation productivity (Lankford and Gillingham, 2001). Pragmatic use and management of rainwater in existing farm infrastructure, taking into account the likely contribution of rainwater to irrigation water, is an alternative option for increasing productivity of water in irrigated agriculture.

This paper examines the use of rainfall for increasing productivity of water using a case study of the NAFCO [2]—Kapunga rice farm. Four main advantages could be obtained as a result of using rainfall water in the period between the last decades of December and January for field wetting and rotavation. First, by avoiding early transplanting of rice and concentrating rice paddy activities during the window that matches with adequate rainfall, water is reserved more for domestic and environmental demands during the lowest river water levels (October–December). Secondly water is saved from being used in activities that require high quantities of water such as wetting of paddy fields for rotavation and transplanting; thirdly a more focussed planting period could stabilize the market of rice yields through reduced harvesting gap between early and very late transplanted rice; and fourthly, the practice improves productivity of water in irrigated rice paddy.

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[1] A theory that if an inefficient irrigation system is replaced by a more efficient one, usually at a substantial cost, the result may be a zero-sum game where apparent gains at the beginning of the water cycle are off-set by losses of return flows in the rest of the water cycle.

[2] Stands for National Agriculture and Food Corporation, a government parastatal organization with mandate of running large National Farms in Tanzania.

2. Methodology

2.1. Description of the study area

The study was carried out in the upper catchment of the Great Ruaha River (GRR) basin in Usangu plains between 2000 and 2003 as part of SMUWC and RIPARWIN works.[3] The Usangu plain is located in the southwest of Tanzania between approximately latitudes 7°41′ and 9°25′ South, and longitudes 33°40′ and 35°40′ East. The area is situated at about 1040 m above sea level. The general climatic pattern is tropical wet-and-dry characterised by uni-modal type of rainfall, moderate to high temperature, low wind speeds, and high relative humidity. The average mean annual and effective rainfalls received in the area are 669 and 479 mm, respectively. The GRR is a main tributary to the Rufiji River, which forms the largest drainage basin in Tanzania, covering some 174,800 km^2, which is about 18% of Tanzania Mainland. The total area of the Usangu plains is 20,811 km^2, about 12% of the total Rufiji basin. From Usangu plains, the GRR passes through intermediate wetlands in the plains and it then flows to the Ruaha National Park.

Two NAFCO rice irrigation schemes covering 17% of a maximum wet season rice irrigated area of 45,000 ha are located within the upper GRR in Usangu plains. These farms, Kapunga and Mbarali, receive water from two major rivers, the Great Ruaha and Mbarali, respectively. The entitled water rights for wet season paddy irrigation of the farms are 4.8 and 6.0 m^3, respectively. The season for irrigation in the farms starts from October each year and extends up to June/July. Water levels in these major rivers are lowest in the period from October to December of each year. The total area put under irrigation normally changes from one season to another depending on a number of factors such as weather condition and financial ability of the schemes to cultivate the farms per season but the maximum area that can be irrigated is 7650 ha during the wet season. Other rice irrigation schemes managed by smallholders in the area include the Kimani (2269 ha) and Madibira (4502 ha) farms.

2.2. Data collection and analysis

A water balance approach was applied to quantify the components of water use at field scale. The irrigation inflows and outflows for the paddy field plots (6 ha) were measured using inlet and outlet gates available for each field every time when irrigation application and draining events were done. The gates were calibrated once per season for four seasons by current meter measurements using rating tables developed during construction of the farm. The inflow and outflow measurement were used to estimate the amount of water used in the field during the entire crop growth period. Crop transpiration, surface evaporation and field water losses (seepage and deep percolation) were measured using microlysimeters. The lysimeters were constructed using cylindrical plastic drums each with a volume of 4.26×10^{-2} m^3. Three lysimeters were installed half of their lengths below the soil surface in two sampled rice paddy fields at a distance of 100 m consecutively along one line for each season. The first microlysimeter (bottomed) transplanted with some rice seedlings was used to monitor transpiration of rice crop. The second lysimeter also bottomed was used to monitor surface evaporation and also the effect of crop canopy on surface evaporation during the crop growth period. The third lysimeter (bottomless) was used to monitor sub-surface and deep percolation losses to the ground. The change in levels of water in the lysimeters due to rice transpiration, open surface evaporation and sub-surface and deep percolation losses was monitored using a hook pointer fasted to the lysimeters and the pointer levelled to the water surface every day at 09.00 GMT once the measurements has been made. Portable Rainfall gauges were used to account for increase in water level in the lysimeters during rain days. Estimates of crop water requirements obtained from reference crop evapotranspiration (Et$_0$) and crop factors (K_c) were used to check crop evapotranspiration obtained from lysimeter measurements. The rice yield harvested from sample quadrants was measured twice using a weighing balance during harvesting and storage (18% and 15% moisture contents, respectively). These yields were used in estimating average crop yield per hectare from the fields and the productivity of water to rice was determined as a ratio of yield to water used per hectare.

The seasonal decadal rainfall values were computed using rainfall data for a period of 10 years to give the average estimate values of rainfall onset and cessation over a long period in the study area. The data was obtained from a weather station located in the irrigation farm. The decadal mean rainfall values were expressed as a percentage of the total mean annual rainfall and then a plot of the mean percentage cumulative seasonal decadal rainfall was made. Then a plot of the mean percentage cumulative rainfall values against decade numbers for the years of records was plotted. The analysis from the plot comprised calculation of (a) the time of onset of rainfall defined, as the time that corresponds to the point of maximum positive curvature of the plot of cumulative expected decadal rainfall; (b) the time of cessation of the rainfall defined, as the point of maxi-

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[3] 'SMUWC stands for Sustainable Management of the Usangu Wetlands and its Catchments (1998–2001) and RIPARWIN' stands for Raising Irrigation Productivity and Releasing Water for Intersectoral Needs (2001–2005). Both are DFID funded research projects based in Usangu Plains in Tanzania.

mum negative curvature on the plot of cumulative expected decal rainfall; and (c) the average seasonal rainfall was calculated as the difference in time between the onset and cessation of rainfall. The likely contribution of rainfall water (effective) in the irrigation farms and its associated percentage increase in productivity of water were estimated from the months with almost zero dry spells which is between December and February (Makungu et al., 1998). The associated increase in productivity of irrigation water was determined by subtraction the contribution of rainfall water from the gross depth of water applied.

3. Results and discussion

3.1. Water balance analysis

The water balance analysis indicates that about 644 mm of irrigation water in paddy fields was used for wetting up the fields during land preparation, 273 mm as deep percolation losses to the ground and 133 mm as standing water layer in the fields mainly lost through surface evaporation. The total water requirement to meet irrigation depth of 1800 mm with an effective rainfall of 500 mm was about 2300 mm. The mean annual crop evapotranspiration in Usangu plains calculated using the Penman–Monteith method was 1939 mm.

Land preparation and field wetting in particular consumed about 28% of the gross amount of water used for irrigation. This amount was attributed to the use of water as a tool to suppress weeds and to level fields. This resulted in a longer time for water to be available to downstream farms and contributed to about 12% of gross water loss to the ground. This was also a major reason for the prolonged period with which rice field stayed with water from the start of rice field operation up to harvesting. In the early years of irrigation development it was assumed (Hazelwood and Livingston, 1978) that the NAFCO farms would plant early, use machinery and take advantage of higher temperatures at the end of the season. Under those arrangements paddy field watering would have lasted for about 160–170 days for a 5-month crop. The total period for water abstraction would be 215 days during October–April (Franks et al., 2003). Currently, field watering is extended up to 260 days, which is approximately 300 days on gross water use basis.

The increase in period with which fields stay with water is also partly due to problems of mechanised operations and the patterns of labour availability. The overall effect is to increase the effects on river abstraction up around 60% (SMUWC, 2001) in the dry season. During this period of time, the natural flows (Fig. 1) in the rivers are small and the effects of this magnitude cause negative consequences to the wetlands and downstream uses. Greater use of water over an extended period results in relatively low water use efficiency and productivity of water being in the range from 12% to 46% and 0.10 to 0.28 kg/m^3, respectively for individual rice farms.

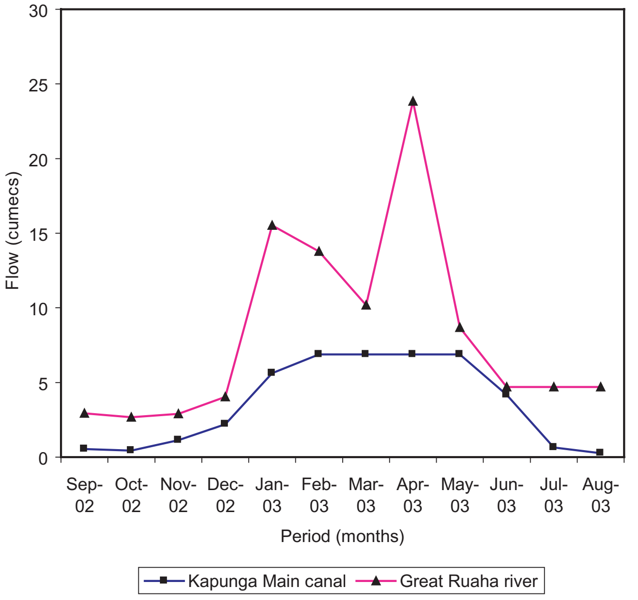

Fig. 1. Great Ruaha River and NAFCO Kapunga main canal flow hydrographs from September 2002 to August 2003.

3.2. Rainfall use and enhancement to productivity of water

The productivity of irrigation water in the NAFCO fields can be enhanced through conjunctive use of rainfall between the windows starting from mid December to the end of January. Analysis of on set and cessation of rainfall indicates that the period is desirable on three fronts: first the on-set of rainfall does not go beyond the first decade of December and by January the depth of rainfall of more than 200 mm stored in the soil is sufficiently enough to allow operation of field activities for paddy crop; secondly the amount of rainfall received within the period constitutes a large percent (40%) of the mean annual rainfall, which is also about 36% of the total water used for land preparation especially for wetting the fields. Despite the fact that the rainfall received in February might be high, during this period and later, most of the field preparation for rice transplanting and transplanting itself is normally on the verge as 20th of February is always the last date for late transplanted paddy in Usangu plains but rainfall during this period can only provide pivotal role in reducing the frequency of irrigation in transplanted fields. Transplanting beyond the date of 20th February is associated with biologically low crop yield and hence low productivity of water, and thirdly the probability of dry spells during the period decreases almost to zero indicating a

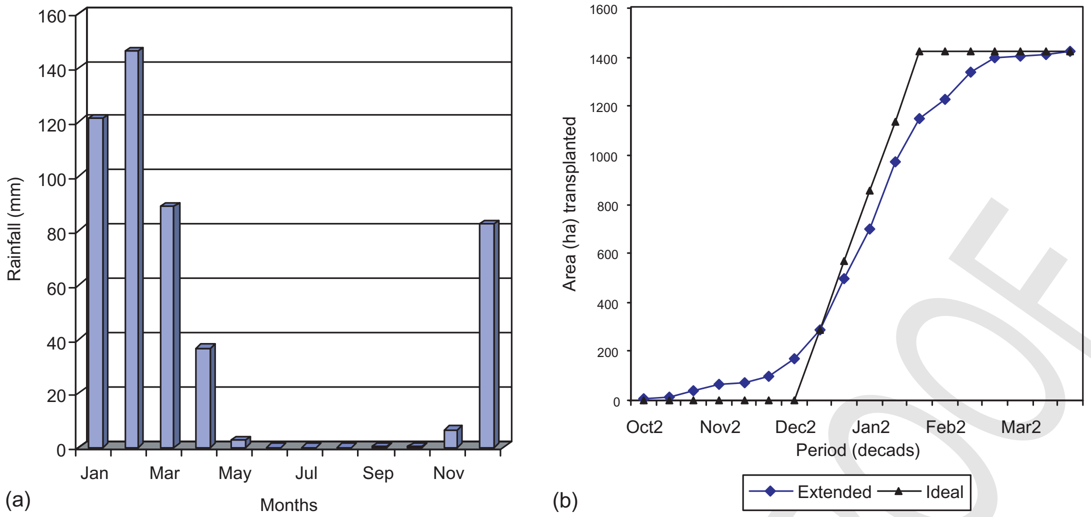

Fig. 2. Monthly rainfall over 12 months and the extended and ideal transplanting rates for NAFCO Kapunga farm: (a) average monthly rainfall in the study area, (b) extended and ideal transplanting rates for NAFCO Kapunga.

favourable window where rainfall water can be conjoined effectively with irrigation water to increase the productive use of irrigation water for paddy.

The current productivity of water at farm level (0.13 kg/m^3) was estimated from the gross water use of 2300 mm (irrigation water + rainfall). This value does not take into consideration the seasonality and possibility for conjoining rainfall and irrigation water. Low values of productivity of water are attributed to increased amount of water, which is used for land preparation about (644 mm). The practices of flooding and maintaining high depths of water in paddy fields to soften the soils and suppress weeds encourage much losses of water through deep percolation and evaporation and contribute to low productivity of water, since the same water is considered as part of irrigation water. The effective rainfall received between mid December and end of January, which is about 36% of the total amount of water used for land preparation, when effectively combined with irrigation water within the period, may result into reduction of gross water use to about 2100 mm. The reduction in gross water use may result to increase in productivity of water of up to 0.14 kg/m^3, which is an increase of about 9% from the current level. However, the contribution of rainwater considered here has not been given priority under normal arrangements because of the failure to match the period when rainwater can effectively contribute towards enhancing productivity of irrigation water at the farms. The determination of productivity of water was done based on average paddy crop yield of 3 tons/ha. However, the amount can further be improved to above 0.3 kg/m^3 when proper timing of rice operation, agricultural inputs and good water control are ensured. The saving of water through conjoined rainfall and irrigation water approximates to 3 mm^3 over about 1500 ha and this can be reallocated intra or intersectorally to the most needy users. The saved amount can for example, be used to irrigate an additional agricultural area of up to 214 ha under the gross irrigation depth of 1400 mm. This may include the area cultivated by tail ender irrigators who normally have to wait for water until it is released from the NAFCO farms. This may also allow a timely transplanting for the tail ender irrigators and in so doing help stabilize the market for rice between upstream irrigators and the tail ender water users. Experience has indicated that farmers who transplant earlier receive as twice as much the price received by downstream farmers who transplant late in the season.

A large percent of rain falls between December and January reaching a total of 220 mm (Fig. 2). On the other hand, under ideal condition, transplanting could take only one month and three weeks (3rd decade of December to 1st decade of February). However, extended transplanting takes up to seven months (from 2nd decade of October to the 1st decade of April) making a difference of five months. The transplanting pattern indicates partly the reason for the low values of productivity of water in the study area. As depicted in Fig. 2, it is clearly evident that extended transplanting is unnecessary especially at the earlier part of the season because large percent of transplanted area is between December and January, which coincides well with the ideal transplanting pattern.

4. Conclusions

The findings in this study show that productivity of water can be improved up to 9% from the current level if rainfall and irrigation water are used effectively between the last decades of December and January. The amount of water saved may not be seen as significant when compared to the total amount used, but it may play an important role. It may provide a mechanism for shifting rice paddy activities from the period when water is critically required for environmental functions to a period when rainfall water can efficiently be used conjunctively to coincide with a nearly non-limiting irrigation supply. This also offers an opportunity to release some of the water to the most needy tail-ender irrigators who normally receive water two months later after the rice farms. Since the stabilisation of market price is an advantage to the tail enders, it can also play as a pro poor strategy for increasing water productivity among the poor farmers downstream the Kapunga NAFCO farm.

Substantively, this case study shows that productivity of water can be managed by considering timeliness and coincidence of water supply. When reflecting on the three main ways that productivity can be enhanced (Molden et al., 2001), this time-management aspect of water productivity is a sub-set of means to save water. Yet, while many authors contemplate physical interventions, we argue here that practical means, which more explicitly recognise time and timing of water use, can be deployed to raise productivity of water resources.

5. Uncited references

Lankford (2001a,b).

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