Importance of water consumption by perennial vegetation in irrigated areas of the humid tropics: evidence from Sri Lanka

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Abstract

In tropical, monsoon climates of South-East Asia, irrigation facilities supplement rain in the wet season and enable crops to be cultivated during the dry season. In the Dry Zone of Sri Lanka, 70% of the average annual rainfall of 1000 mm falls in a 3 month period. During the dry season, reference evapotranspiration has less rainfall — about 700 mm, indicating that much additional supply is meant to support crops, mainly paddy. In this climatic context, irrigation has dramatically changed the local environment, creating ecosystems quite similar to that of the wet zone to flourish. In these systems, recharge of shallow groundwater by percolation from irrigated fields, canals, and tanks, has provided a continuous supply of water for natural vegetation and homestead gardens. Much of the water used by this non-crop vegetation is beneficial. Growth of fruit and coconut trees can be quite profitable, while other trees enhance the environment.

In 1998, IWMI performed a comprehensive water balance in the command area of the Kirindi Oya irrigation scheme, Sri Lanka, based on surface flow measurements, rainfall data, and estimation of crop water requirements. This water balance showed that evaporation consumed 78% of the total amount of water available for use. The amount of evaporation is split into process depletion (crops for 28%), direct evaporation from tanks (7%), inter-seasonal fallow (10%) and from non-crop vegetation for 55%.

The main conclusion from this study is that perennial vegetation as the main component of non-crop vegetation, is a significant consideration in tropical humid environments in planning, management and performance assessment. Designers, managers, and researchers need to specifically incorporate the evaluation of evaporation by non-crop vegetation and perennial
vegetation in their approach of water requirements. Further investigation is needed to estimate water consumption by land cover type to assess their respective beneficial use. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Irrigation management; Humid tropics; Perennial vegetation; Evapotranspiration; Water balance

1. Introduction

In monsoon areas of South-East Asia, irrigation facilities supplement water supplies for rice during the monsoon, and store additional water to be used on crops during dry seasons. Irrigation water delivery requirements are typically calculated by considering the net evapotranspiration requirements of rice (potential evapotranspiration less effective precipitation) plus amounts required for seepage and percolation for rice (Bhuiyan and Undan, 1990). Irrigation requirements for an area are determined by dividing requirements at the field by the product of conveyance and application efficiency. Performance is often evaluated against delivery of these requirements. But, it is now well recognized however that aggregation of irrigation requirements in this manner does not lead to a comprehensive and consistent picture of water requirements. Water recycling, such as that found in the tank cascades of Sri Lanka (Sakthivadivel et al., 1996), is not factored into these classical design and performance criteria.

Furthermore, water developed primarily for irrigation tends to find many uses beyond the supply of water to crops. Developing water for irrigation has had positive and negative impacts on water for domestic, environmental and industrial uses. Irrigation in tropical regions often provides benefits far beyond crop production (Bakker et al., 1999).

In the dry zone of Sri Lanka, irrigation in old schemes has led to dramatic changes, creating an environment where perennial vegetation and homestead forestry gardens, usually only found in the wet zone, thrive. High groundwater levels induced by irrigation, provide a source of water for horticultural trees, mostly coconut, to sustain growth even during dry periods (the Yala season in Sri Lanka from April to October). Other trees grow naturally under these favorable moisture conditions.

It is not surprising that perennial vegetation can consume such a large proportion of the total amount of water made available in a given irrigated area. More surprising is that little consideration has been given to water consumption by trees and other non-crop vegetation within irrigated areas. Only a few studies could be identified reaching similar conclusions (Abernethy, 1985; WMS, 1987). A few reasons can be identified for this oversight. Much of our efforts have been focused on the delivery water to farmers or to crops. We have not paid attention to other non-crop water use. Second, with increasing attention being paid to water scarcity, more focus is placed on the overall water balance of irrigated areas. In this context, other types of consumption besides crop consumptive use becomes more important.

This study focuses on the Kirindi Oya Settlement Project situated in South-East Sri Lanka. A preliminary water balance survey was made in a limited command area (2000 ha) of the old irrigated area during 45 days in the dry season of 1996. This water
balance indicated that half of the total consumption during the dry season was through evaporation by perennial vegetation covering about the same area as paddy (Mallet, 1996). To address this issue more carefully, IWMI carried out a 1 year study in 1998 on the entire area of the project with the goal to measure or estimate the main outputs of the water balance and more specifically assess the consumptive use by non-crop vegetation.

In irrigated areas, non-crop vegetation is composed of both perennial (trees) and non-perennial vegetation, such as grass on the bunds of paddy fields, along canals, ditches and roads. In the context of Sri Lanka, perennial vegetation is largely dominant in the old irrigation systems. Therefore this paper addresses primarily perennial vegetation as it dominates non-crop water consumption at Kirindi Oya.

The objective of this paper is to alert managers of similar type of irrigation systems on the importance of incorporating perennial vegetation in the management of irrigation systems. This is important because the degree of water use and benefits derived from perennial vegetation is not well understood and rarely taken into consideration by management. This is especially true in humid, tropical areas, where water consumption by non-crop vegetation can be very significant. This paper provides evidence of beneficial use by unintended uses of irrigation water, illustrates a means to quantify this use, and suggests how incorporation into performance measures and management could be done.

The importance of water consumption by perennial vegetation must be both understood in terms of water consumption and in terms of non-intended but beneficial outputs. Design of new irrigation system as well as performance assessment and operation of existing systems must be undertaken with consideration on perennial vegetation within the irrigated command area.

1.1. Background on perennial vegetation

Perennial vegetation, whether planted on homesteads, or growing naturally in irrigated areas, has contributed substantially to improve the environment as a whole (Wickramasinghe, 1992). There are many benefits to the presence of perennial vegetation:

- It provides shade and coolness, and provides an escape from the harsh tropical sun.
- It allows for increased bio-diversity within the ecosystem.
- Homestead forestry garden is an important source of income for farmers.

In Sri Lanka, irrigation developments have been made with the goal to provide settlers with irrigated paddyfield of 1 ha and a homestead plot of land of approximately 0.2 ha. Established farmers in the area may possess greater areas in paddy and homestead. As in other regions such Kerala in India, (Salam and Sreekumar, 1991) homestead gardens in Sri Lanka are of great importance for farmers to provide them with food, medicinal plants, fuelwood, a pleasant environment, and raw materials for handcrafts (Fig. 1). One of the favorite trees planted by farmers in their forestry garden is coconut palm tree which is called ‘the tree of life’ because every part of it is used (Persley, 1992): meat, leaves, cocoshell, husk, trunk, cocowater, and roots. In addition to homestead gardens, natural
vegetation along rivers, ditches, canals and represents another source of water depletion which has to be accounted for in water balances.

2. Impact of perennial vegetation on the water balance

Perennial vegetation has two major effects on the water balance:
- A reduction of the potential contribution of rainfall to crops; and
- An increase in evaporative depletion of water resources within the irrigated area.

It is well known that perennial vegetation reduces the rainfall contribution to run-off because of interception. Part of the rainfall is intercepted by the canopy, and evaporates directly without reaching the ground. Values of interception coefficient (percentage of rain that is evaporated by the process of interception) can be found in the literature, although there are discrepancies between authors. Basically the interception coefficient varies with the density of vegetation and with the regime of rainfall. Interception in tropical areas is usually less than in temperate climates. For the latter, frequent rains of low intensity can lead to values as high as 40% as reported by Calder (1993, 1998). For tropical forests, reported values are 13% for Amazonia to 21% in Indonesia (Calder, Fig. 1. Picture showing a typical homestead in irrigated areas (Sri Lanka).
1993), 17% in lowland rainforest of Malaysia to 20% in the Philippines (Bruijnzeel, 1997). Balek (1977) cited in Radersma and de Ridder (1996), estimated that 70–80% of precipitation reaches the soil below rainforests (20–30% of interception).

Tropical perennial vegetation transpires on a continuous basis throughout the year. Because roots can tap groundwater, transpiration rates are at full level during much of the year. Therefore, it was hypothesized that consumption of water from perennial vegetation in irrigated areas is high in terms of volume per unit area at Kirindi Oya.

The source of water for perennial vegetation is directly from rainwater and indirectly from irrigation supplies. Irrigation supplies and rainwater percolating past the root zone enters a shallow groundwater system where it can be tapped by tree roots. Without extensive vegetation, part of this water would have re-entered the drainage system and been available for crop evapotranspiration, or would flow out to the Indian Ocean.

2.1. The study site

The Kirindi Oya settlement project, completed in 1986, is located in the dry zone of Sri Lanka. Average annual rainfall is 1000 mm with a dry season (Yala season) from April to October. Minimum average temperatures vary from 26°C in December to 28°C in April. Values of reference evapotranspiration vary from 110 mm in November to 184 mm in August, with an annual value of 1765 mm.

The project, (see Fig. 2), consisted mainly in the construction of a new important reservoir (Lunugamwehera) meant to

- secure supply to the existing old system, ‘Ellegala’, of approximately 5000 ha (EIS);
- develop new areas on the left and right banks of the Kirindi Oya river, upstream the old system, for another 5000 ha (NIS) to serve the needs of new settlers.

The old system has been under production for centuries, while the new system has delivered water since 1986. One major visible difference between the two systems is the density of perennial vegetation, the old system is covered with dense and tall trees, while perennial vegetation is still sparse and under development in the new system.

For domestic use, settlers in the new areas receive treated water from the Luhunugamwera Reservoir, while farmers in the old areas rely on private wells.

The project is located on the downstream part of the Kirindi Oya Basin, immediately before the river reaches the Indian Ocean. Several peculiar features of this area are important for the understanding of water management:

- it is a tank cascade system where drainage water is captured in downstream tanks and recycled again for irrigation. It is estimated that 66% of the water delivered to the NIS command area is recycled downstream in the EIS;
- excess drainage water flows into the Indian Ocean in excess of downstream environmental needs, and the basin is considered open (Seckler, 1996);
- part of the old Ellegala system, is considered as a wetland sanctuary site of international importance (Wetland Conservation Project, 1994);
- coastal areas are made of several brackish water lagoons where ocean water is mixed with fresh drainage water. The lagoons on the west side of the project form the Bundala
Fig. 2. Map of Kirindi Oya settlement project.
National Park (Matsuno et al., 1998). It is believed that salinity levels in the lagoons are dropping below the natural level because of excess irrigation drainage flows, thus endangering the natural ecosystem.

2.2. Problem description

Since its implementation, the project has supplied the whole area during the wet season, but it has not been able to provide enough water to sustain a second crop during the dry season for the entire project service area. An over-estimation of water availability is often advanced as the reason for the gap between designed and actual irrigated areas. However, it is clear that water requirements have been based only on estimations of requirements for paddy (rice) without taking into account additional evapotranspiration from perennial vegetation. This is a major reason for the discrepancy between predicted and actual consumption.

Kirindi Oya is not an isolated example of this type of problem. All the major irrigation schemes in Sri Lanka (400,000 ha) in the dry part of the country are significantly covered with perennial vegetation. This situation is also very common in many areas of the humid tropics worldwide.

2.3. Perennial vegetation at Kirindi Oya

In Kirindi Oya scheme, perennial vegetation has largely developed over time and now covers a great part of the area (Fig. 3). It must be stressed that the importance of perennial vegetation is the result of paddy cultivation. Other crops and other irrigation techniques at the field level would have led to a completely different picture. A survey made during Yala 98 has shown that on average groundwater depth in the old Ellegala system (low and flat lands as shown in Fig. 3) varies from 1.6 to 2.8 m. Tree roots can readily tap groundwater of this depth even in the dry season.

![Schematic cross section of KOIS Project.](image-url)
Vegetative coverage in the Old System (EIS) is much more than the New System (NIS) for three main reasons:

1. **Historical**: the old system has been in existence from ancient times, while the new system development is recent (14 years);
2. **Topographical**: the light soils of the undulating NIS command area are quickly drained once irrigation is cut off;
3. **Managerial**: so far the intensity of irrigation in NIS has been low, reaching only 103% per year (Renault, 1997), i.e. one crop per year, which does not allow to sustain wet zone type perennial crops throughout the all year.

Aerial photographs confirm the importance of perennial vegetation in the area. Even in urban areas (called settlement areas and/or homestead gardens), the density of perennial vegetation is important. In homestead gardens, the vegetation is generally developed in three layers. The highest is composed of coconut trees, the medium of fruit and medicinal trees and the lowest of vegetables and grass. It can be concluded that the whole area is an evaporative surface made of paddyfields, fallow lands, water bodies and perennial vegetation.

It must be pointed out that perennial vegetation is also found in non-irrigated areas of the dry zone. It is, however, mainly composed of shrubs and small and drought adapted trees which evaporate much less than their well fed counterparts of irrigated areas and in the Sri Lankan wet zone.

2.4. **Water balance**

During the 1998 calendar year, measurements were carried out to establish a water balance within the scheme. The water accounting figures are displayed in Fig. 4 and Table 1, following the framework proposed by Molden (1997). Details about measurements and evaluation are given further.

2.4.1. *The studied gross command area*

The water balance domain is shown in Fig. 2. The domain does not completely coincide with the entire command area because of the points selected for reliable

<table>
<thead>
<tr>
<th>Inflow (Mm³)</th>
<th>Outflow (Mm³; %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation</td>
<td>Rain Storage Variation NET INFLOW Committed Available Available Uncommitted crop process depletion Non-process depletion</td>
</tr>
<tr>
<td>245³</td>
<td>230³</td>
</tr>
<tr>
<td>100%</td>
<td>22%</td>
</tr>
</tbody>
</table>

*a Measured.

*b Estimated.

*c Measured + Estimated.

d Closure of the balance.
measurement. Part of the downstream left bank in the EIS and parts of the right bank
main canal in NIS are not incorporated in the water balance. Drainage from these areas
was not measured. The water balance domain is bounded by the main canals in the north
and the limits of the outflows catchment areas in south, the impermeable layer of the
underlying aquifer, and is taken for a 1 year time period (1 January–31 December 1998).
The water balance domain area covers a Gross Command Area (GCA) of 25,638 ha as
measured from a remote sensing image.

Fig. 5 displays the monthly recorded values for 1998 of reference evapotranspiration
and rainfall. Reference evapotranspiration in 1998 closely follows the average pattern. In
1998, the total of Eto was estimated at 1785 mm compared to an average annual value of
1765.

2.4.2. Gross inflow

2.4.2.1. Rainfall. Rainfall is measured at three locations within the scheme. The average
rainfall on the domain for 1998 was 897 mm, which is 10% less than the long term average.
The input from rainfall has been estimated for the GCA to be 230 Mm$^3$ (million cubic
meters=$10^6$ m$^3$), which might be considered as a minimum given the presence of external
small watersheds (not accounted for).

2.4.2.2. Irrigation. Deliveries from the Lunugamwehera reservoir to the main Left
Bank Canal and Right Bank Canal (Fig. 1) are measured twice a day. A total of
246 Mm$^3$ was delivered during 1998. Thanks to heavy rains in late 1997, water resources were abundant in 1998 and the irrigation intensity reached 200% on an irrigated area of 8619 ha.

2.4.3. **Net inflow**

The net inflow is the gross inflow minus the storage variation. In the domain under consideration there are three types of storage, surface, subsurface and groundwater. The surface storage is made of four major tanks in the old system totaling a capacity of 27.4 Mm$^3$. The storage volume decreased by 2.7 Mm$^3$ between the 1st of January and the 31st of December. The subsurface storage includes the water stored within the soil matrix under irrigated fields. Given the fact that the area under irrigation has not changed, it is assumed that there is no subsurface storage variation between the start and the end of the year study. The main groundwater aquifer is predominantly situated under the flat alluvial plain of the old area (Fig. 3). It is also assumed that there was no significant groundwater storage variation during the study period. December is in the middle of Maha season (wet), and groundwater is typically at the highest level due to the conjunction of inputs from both rain and irrigation.
2.4.4. The depleted flows

2.4.4.1. Process depletion. Water that is depleted by intended uses is considered process depletion (Molden, 1997). Water is delivered primarily to irrigation use. Other process depletion is through the piped water system delivering water to households, but the amount of this water entering the water balance domain is considered negligible. At times, water is intentionally released in the canal for bathing, but it is assumed that this is not depleted, rather it enters the groundwater system and is available for use (Van Eijk, 1998).

Crop evapotranspiration has been estimated for the period of reference, using Pan Evaporation data recorded at Lunugamwehera reservoir with a conversion factor of 0.85 (Doorenbos, 1976) and standard crop coefficients. For the 8619 ha irrigated within the GCA of the studied area, the crop consumption was estimated to be 95 Mm³. For the 1998 Yala season (dry), the evaporation was estimated at 720 mm. Monthly averaged value for Maha season (128 mm) is much lower than for Yala (180 mm). The study year was slightly unusual in that due to late rains, the 1998 Maha season (fall) was delayed by 1 month. Therefore, the water balance during the calendar year 1998 does not cover entirely two crops. For a normal annual cycle, the corrected figures for crop consumption would be slightly greater and approximate 100 Mm³.

2.4.4.2. Non-process depletion. Non-process uses are natural and other unintended uses of the water resource. Non-process depletion is mainly evaporative depletion by non-crop vegetation, inter-season fallow and free surface (water bodies). At Kirindi Oya, consumption by perennial vegetation is considered non-process because management does not deliver water to this use. If decisions were made to intentionally supply water to trees, either directly or indirectly, depletion by perennial vegetation would be reclassified into process depletion.

Out of the 25,638 ha of the gross command area, only 8619 ha are irrigated (see Table 2). The remaining part (17,019 ha) includes different types of land uses such as water bodies (tanks), urban areas, homestead garden, forests, canals, and roads. While there have been studies of evaporation from tanks, this study represents the most comprehensive approach to estimating non-process depletion at Kirindi Oya. An on site survey as well as study of aerial photographs show that non paddy areas are covered to a large extent with vegetation even in urban areas. Therefore, it is no surprise that water consumption for this land use and for non-process depletion is very high.

<table>
<thead>
<tr>
<th>Land use</th>
<th>Annual averaged depletion (mm)</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total paddy field</td>
<td>1460</td>
<td>8619</td>
</tr>
<tr>
<td>Fallow period²</td>
<td>300</td>
<td>8619</td>
</tr>
<tr>
<td>Dry and wet seasons crop²</td>
<td>1160</td>
<td></td>
</tr>
<tr>
<td>Water body</td>
<td>1520</td>
<td>1600</td>
</tr>
<tr>
<td>Non Crop Vegetation</td>
<td>1200</td>
<td>15419</td>
</tr>
</tbody>
</table>

² Corrected to consider two entire seasonal crops.
The water consumed by perennial vegetation has been classified into one single category: non-process beneficial. However, there is a need to distinguish sub-classes within the vegetation, from high dense perennial vegetation (beneficial) to shrubs (low beneficial).

Evaporation from fallow land and free water surfaces is categorized as non-beneficial. The amount of water evaporated from fallow lands is computed from the Pan evaporation records with a crop coefficient of 0.5. The total amount estimated then for the fallow period is 32 Mm³, which represents an average 74 mm per month. The evaporation from water bodies (tank) was estimated using the entire area covered by the tank at full supply level, and the Pan evaporation measured at the main reservoir. The estimated amount of evaporation for the whole year is 24 Mm³. Given the shallow-depth in the tanks, it is assumed that evaporation does not decrease significantly with water level. When waterlevel drops, the exposed soil of the tank is assumed to be above or near saturation due to lateral movement of water from the tank.

The water consumed by perennial vegetation in the GCA has not been directly assessed, but is calculated firstly as the closure term of the water balance. As such it incorporates of course all the uncertainty attached to other terms. From the closure of the water balance it is estimated that 184 Mm³ of water are consumed through perennial vegetation, representing an average 1200 mm/year. This figure is a spatial average within the GCA, it is expected that local non crop-vegetation consumption varies from high values for high and dense trees in the old area to low values for smaller and less dense trees in the newly developed areas.

2.4.5. The outflows — committed and uncommitted

Outflows from the water balance domain that are required downstream, or intentionally released for downstream uses are classified as committed outflows. Part of the reservoir releases that flow downstream of the study area are considered committed outflows. On the Right Bank Canal, an estimated volume of 26 Mm³ was released to Tracts 6 and 7. An estimate of 21 Mm³ was discharged to the Left Bank area falling outside the study area during the 1 year period. These outflows were estimated as a proportion of the total issues from the main reservoir, based on the command areas. The second committed outflow is for Bundala lagoon and for environmental requirements in the Kirindi river. It is assumed that the drainage flows which are included in the committed irrigation discharge allocated for Tracts 6 and 7 and for part of the old area are sufficient to meet these requirements.

The uncommitted outflows from the scheme were measured twice daily at two locations: (1) along the Kirindi Oya river close to the mouth, and (2) at the drainage from Tract 5 on RB of NIS (Fig. 2). They are 28 and 68 Mm³, respectively, totaling 96 Mm³. This is essentially the same value as that of irrigated crop consumption.

2.4.6. Uncertainty on water balance

There are several sources of uncertainty in water balance computations. In this case, we are not certain that the downstream boundary coincides with the catchment area that drains to the measuring point. Second, there are small external watersheds which drain to the main canals. We have assumed this drainage to be negligible. Other uncertainties come with measurement errors and estimates of evaporation and evapotranspiration.
It is well-known that the accuracy of the closure term of a water balance is low because of the inaccuracy associated with the other terms entering the balance. In our case the non-crop vegetation water consumption is the closure of the balance. We made our best estimates of each individual variable entering in the computation of the balance and apply the methodology proposed by Clemmens and Burt (1997) to assess the accuracy. We assumed that the area variables (gross–crop–fallow) are known with 5% confidence interval, fallow land evaporation with 30%, and all other variables and coefficients with 10%. The confidence interval is equal to twice the coefficient of variation of a normal distribution. With these assumptions the resulting confidence interval on non-crop vegetation is estimated to be 24%. Therefore it can be concluded that the amount of non-crop vegetation consumption in Kirindi Oya lies between 140 and 230 Mm$^3$ with 95% confidence.

In spite of the apparently low accuracy, the conclusion remains that evaporation by non-crop vegetation is a dominant component in the balance. On-going investigations are being carried out with the goal to directly measure the water consumption from vegetation using satellite remote sensing.

3. Result and discussions

3.1. Water evapotranspiration

The main finding of this water balance study at Kirindi Oya project is that non-crop vegetation is by far the main consumer of water in the area, consuming twice as much water as crops in the area. The relative amount of evaporation by different land use cover is shown in Table 2. Perennial vegetation has the lowest evaporation rate of 1200 mm, while water bodies show a rate of 1520 mm, and irrigated fields have a rate of 1530 mm. The average value of evaporation for perennial vegetation most likely hides large local variations depending on the water conditions. There is a visible difference in the density and height between trees in the lowlands (plentiful water) and trees in the fringes of the old irrigated system, or in the recently installed new system. The perennial vegetation land use class is much more heterogeneous than the others. Therefore we can assume that many trees might reach similar values of evapotranspiration as water bodies and paddyfields.

3.2. Performance assessment

The annual water input at field level including both irrigation and rainfall amounts to 3350 mm for two crops. This high input is very common in the dry zone of Sri Lanka. In a recent study carried out in a scheme considered as effective (Gal Oya Left Bank covering 16,328 ha of irrigated lands), the average annual water input recorded between 1982 and 1993 amounts to 4250 mm (Amarasinghe et al., 1998).

A classical definition of irrigation efficiency is net evapotranspiration (effective precipitation less of actual evapotranspiration) divided by irrigation diversions (Israelsen, 1950; Keller and Keller, 1997). Using this definition, classical efficiency in Kirindi Oya is
22%, a value normally considered low, but similar to other systems of the dry zone (Kaudulla, Abernethy, 1985).

Using a classical approach we could be led to believe that there is a huge scope for water savings and improvement. This study clearly shows the importance of considering the flow paths of water within irrigated areas. For instance, there is certainly scope for improvement through the reduction of non-beneficial uses of water. But, there is not the scope for improvement as indicated by the value of classical efficiency.

The rate of beneficial utilization defined as beneficial depletion divided by available water is a more appropriate term for evaluating the effectiveness of use of irrigation water (Molden and Sakthivadivel, 1999). Assuming that consumptive use by trees is all beneficial, the beneficial utilization is 66%, a much different picture than that yielded by the classical efficiency definition.

One pertinent question is: how beneficial are various uses of water? Clearly there are tradeoffs between crops and trees. The economic value derived from each of these uses of water is not clear, and there are variations between crops and between trees.

4. Conclusions and perspectives

The main finding of this study is that at the Kirindi Oya project, perennial vegetation is a significant factor in the use of water resources (43%), while only 22% of the available water is really consumed by crops. As perennial vegetation is a common feature of many irrigated areas in the humid topics, it is worth re-thinking classical criteria for design and performance assessment in these areas.

Improving water productivity is a priority for many decision makers and managers, and a reliable water balance is the ground on which strategies for improvements have to be built. This water balance study demonstrated that evaluations based on classical notions of efficiency are inadequate. A better approach is to calculate the rate of beneficial utilization which is the ratio of consumption by beneficial uses to the amount of water available for use in the irrigated area. Classical efficiency calculations yield 22%, while the rate of beneficial utilization is 65%. Classical efficiency does not take into consideration the beneficial use by trees.

The significance of these findings is that common approaches to irrigation management and performance assessment are not adequate to deal with irrigation systems with a high degree of beneficial consumption of water by trees. There is a need for approaches in design, management and performance assessment that explicitly include other beneficial uses of water. This paper gave evidence from location in Sri Lanka. We feel that there are many other locations, where this is true globally.

There is much more research to be done in order to rigorously handle the issue of perennial vegetation and other non-crop uses of irrigation water. Further studies will have to be carried out to investigate the questions that still need to be answered:

- How the accuracy of the measurements can be improved? Particularly how can remote sensing be used to assess non-crop water consumption?
- To what extent perennial vegetation is beneficial?
• What are the sub-classes of perennial vegetation, and how much water do these consume?
• What is the design of a reliable and simple means for managers to assess perennial vegetation?
• How does perennial vegetation in irrigated areas compare with that of non-irrigated areas?
• How can designers, managers, consultants and researchers take into better consideration about the non-crop vegetation in design, management and performance diagnosis?

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